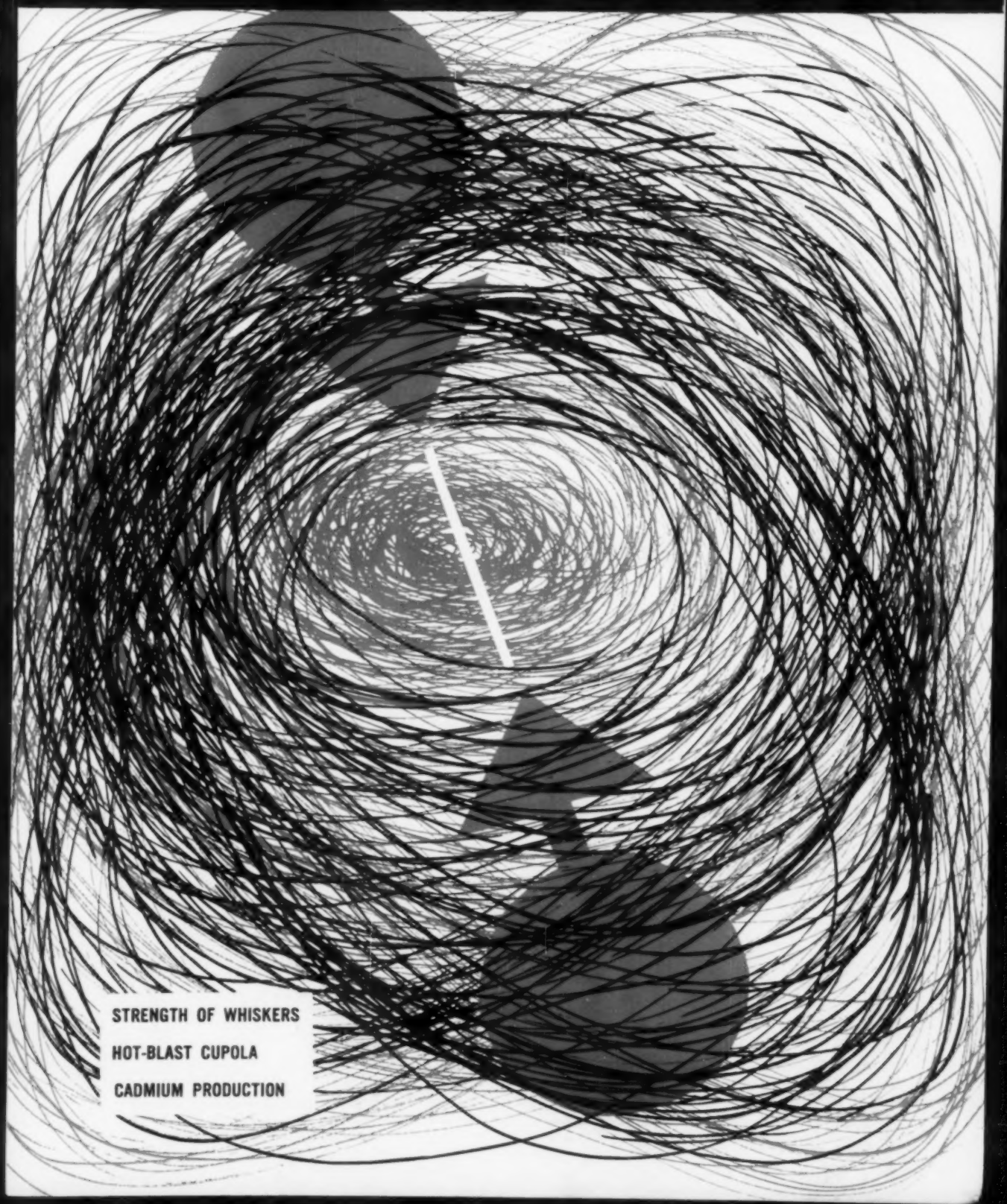
JOURNAL OF

METALS

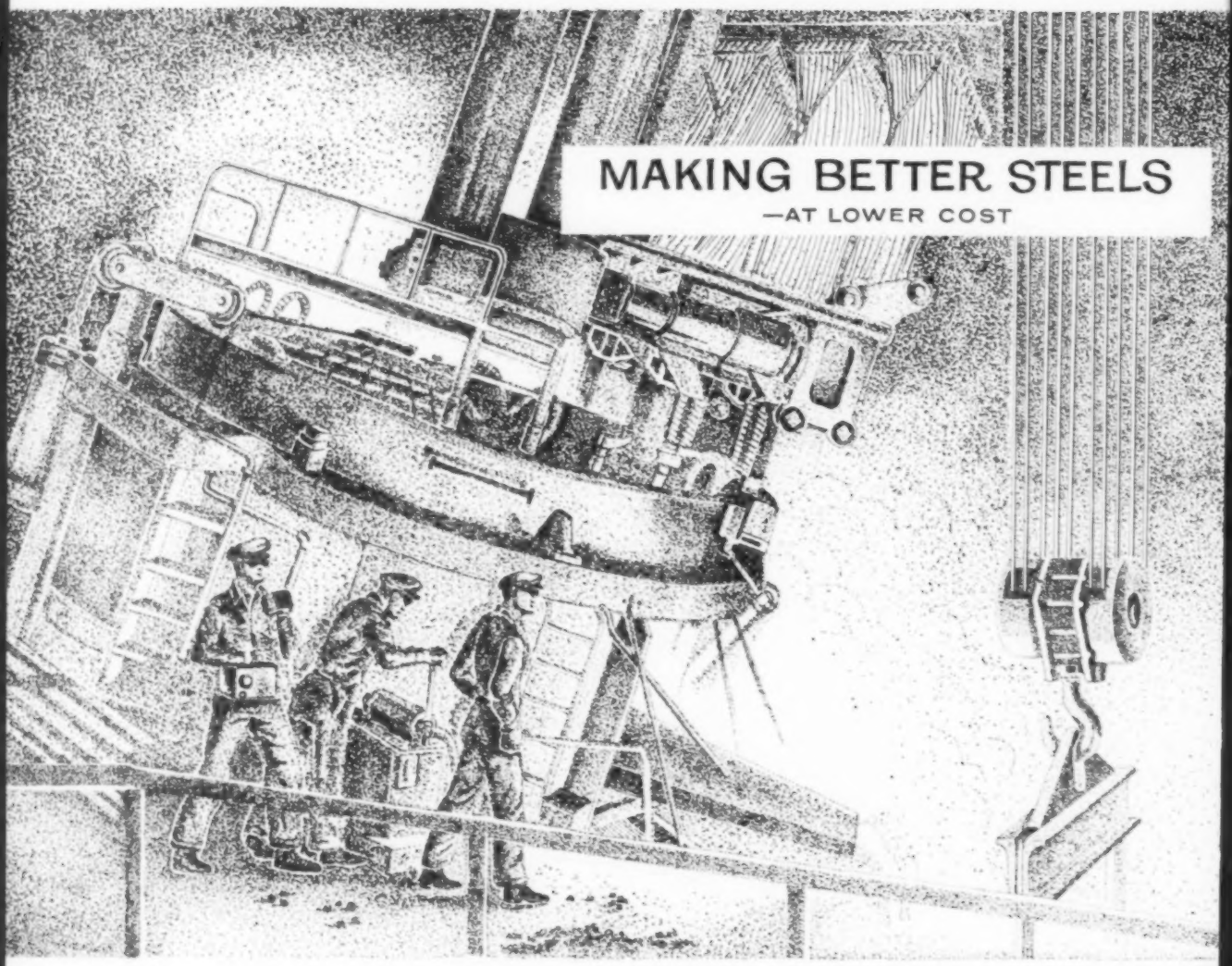
SEPTEMBER 1958



STRENGTH OF WHISKERS

HOT-BLAST CUPOLA

CADMIUM PRODUCTION



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JOURNAL OF

METALS

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September, 1958

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THE following employment items are made available to AIME members on a non-profit basis by the Engineering Societies Personnel Service, Inc. (Agency) operating in cooperation with the Four Founder Societies Local offices of the Personnel Service are at 8 W. 40th St., *New York 18;* 100 Farnsworth Ave., *Detroit;* 57 Post St., *San Francisco;* 84 E. Randolph St., *Chicago 1.* Applicants should address all mail to the proper key numbers in care of the New York office and include 8c in stamps (no stamped envelopes) for forwarding and returning application. The applicant agrees, if placed in a position by means of the Service, to pay the placement fee listed by the Service. AIME members may secure a weekly bulletin of positions available for $3.50 a quarter, $12 a year.

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Position Desired In Management. B.S. Chemistry, age 46. Nineteen years in supervision from foreman to superintendent, open hearth. Three years superintendent of steel production. Location immaterial. M-198 Detroit.

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Metallurgical Engineers for both junior and senior positions, to work either for or in supervisory positions; degree in metallurgy with minimum of two to three years experience. Work entails research and development in a variety of new metallurgical areas including metal powder rolling, conventional powder metallurgy, solid state bonding, arc and induction melting, wire drawing, swaging, etc. Also work in electroless and electrolytic plating and all forms of testing both destructive and non-destructive. Salaries commensurate with experience and ability. Apply by letter giving complete information including standing in class and a listing, and if possible, reprints of any articles that may have been published. Location, Pennsylvania. W6396.

Sales Engineer, B.S. in metallurgy, with from three to five years experience in iron or steel foundry practice, to sell special metals to foundries in Ohio and Michigan. Salary to $10,000 a year. Probable headquarters, Ohio. W6390.

Chief Process Engineer, graduate, to head up process development of plant processing 60,000 tons of crude ore reduce costs. Must be familiar with crushing, grinding, magnetic separation, filtration. Salary, $12,000 a year. Location, Midwest. W6380.

Engineers. a) Physical Metallurgist or Metallurgical Engineer, recent graduate, B.S. or M.S. desired for position involving testing and development in connection with engineering of dryogenic equipment. Salary open. Location, upstate New York. b) Process Metallurgist, M.S. degree preferred, with five to eight years research or production experience in melting practices in iron and steel making. Advanced research—development position in laboratory of leading and diversified company in metals and chemicals industry. Salary open. Location, northern New Jersey. W6371.

Metallurgist, graduate, with some forging experience preferred, for both project and metallurgical engineering. Should have a background in metallurgy and company will train in product engineering. Company's products cover a wide range and variety of flanged fittings for connections and access openings on steam boilers, pressure vessels and tanks. Salary about $8000 a year plus fringe benefits. Location, Pennsylvania. W6349.

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Metallurgist, graduate engineer, with at least 5 years experience in smelter work using electric-ore furnaces for production of ferro-alloys, to instruct and supervise furnace operators in making ferrochrome. Will be responsible for quality control and report to manager of new plant. Salary, $8000 a year. Location, Cuba. S3622.

Process Metallurgist, graduate Met. Engr., with administrative experience in development and production of flat rolled electrical steels. Apply by letter giving education, experience, and availability. Location, South. W6186.

PROCESS METALLURGIST who is imaginative and aggressive with an M.S. degree and five to eight years' research or production experience on melting practices in iron and steelmaking. Must be able to generate new ideas and translate them into commercial applications. Work on the Laboratory engineering staff of a leading and diversified company in metals and chemicals industry in the New York metropolitan area. Submit a detailed resume of education, employment experience, patents and publications, and salary requirements. All responses treated confidentially.

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Includes **all** the information you need to plan a zone melting process, or to decide whether one is feasible. Covers both theory and practice, and spells out the potentialities of crystallization methods as yet unexploited for controlling the purity and precise composition of metals.

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A Collection of Papers Presented at a Symposium on Columbium (Niobium) of the Electrothermics and Metallurgy Division of The Electrochemical Society, May 15 and 16, 1958, Washington, D. C. Edited by B. W. GONSER and E. M. SHERWOOD, both of the Battelle Memorial Institute. Sponsored by the Electrochemical Society, Inc.

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News of EDUCATION

WELDING CONFERENCE

Spotlights will be on the 5th annual Midwest Welding Conference sponsored by Armour Research Foundation of **Illinios Institute of Technology** and the Chicago section of the American Welding Soc., held on January 28 and 29, on the Illinois Institute of Technology campus.

Begun in 1955, the conferences bring together welding researchers and users to discuss current developments in the field.

The program for the January meeting includes some 12 papers dealing with latest developments in processes and applications. Conference sessions will be held in the IIT Chemistry Bldg. at 33rd and Dearborn Sts.

Inquiries concerning the conference should be addressed to *Harry Schartzbart, supervisor of welding research, Armour Research Foundation, 10 W. 35th St., Chicago 16, Ill.*

ATOMIC RESEARCH GRANTS

Research grants totaling $48,428 have been awarded to faculty members of the **University of Michigan,** by the Michigan Memorial-Phoenix Project, a campus-wide activity devoted to finding peaceful uses of atomic energy.

The 14 grants brings to 160 the number of separate efforts initiated by the project which has attracted international attention for its uniqueness and diversity of interest.

PERSONALS

Frederick F. Wood was recently elected an assistant to the vice-president (publicity and advertising) of the International Nickel Co. of Canada Ltd., and assistant vice-president (publicity and advertising) of the company's United States subsidiary, The International Nickel Co. Inc. Wood had been assistant to the vice-president of the U. S. subsidiary since May, 1955.

William T. McCormick, an assistant director of Inland Steel Co.'s medical dept. at the Indiana Harbor Works, has been elected treasurer of the American Industrial Hygiene Assn., at its annual meeting held during the Industrial Health Conference at Atlantic City, N. J.

Norman Brown, associate professor of metallurgical engineering at the University of Pennsylvania, has spent three months at the Max Planck Institute in Stuttgart and is spending a year at the Cavendish Laboratory, Cambridge, since June, on a Guggenheim Fellowship.

(Continued on page 552)

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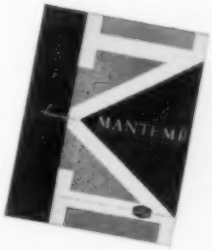

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Personals

(Continued from page 550)

Colonel B. S. Mesick is now assistant to the president, Grand Central Rocket Co., Redlands, Calif.

Robert F. Mehl, of Carnegie Institute of Technology, was recently one of thirty-five men elected to membership in the National Academy of Sciences, Washington, D. C. He is dean of graduate studies, director of the metals research laboratory, and head of the dept. of metallurgical engineering at Carnegie.

Newton H. Johnson, Jr., formerly assistant to superintendent, major alloys div., Niagara works of the Electro Metallurgical Co., div. of Union Carbide Corp., is now assistant superintendent, carbide div. at the company's Ashtabula, Ohio plant.

J. H. Brindle, previously sales engineer with Electro Metallurgical Co., Pittsburgh, is now serving Feedex hot top div., Foundry Services Inc., Pittsburgh, as sales manager.

Walter Bonsack recently joined Aluminum & Magnesium Inc., Sandusky, Ohio, as chief metallurgist. He is advisor to foundries producing for aircraft guided missiles industries on high strength, high purity alloys (aluminum). Bonsack was formerly a consultant on cast light metals in Los Angeles.

Daniel F. Toner, previously assistant professor with the Air Force Institute of Technology, is now associated with Union Carbide Nuclear Co., Oak Ridge National Laboratory as a metallurgist.

Everett E. Klicker has been appointed market research manager for Michigan Chemical Corp., St. Louis, Mich. He will assist the vice-president of sales and development, in extending the markets for the company's basic chemicals and their derivatives. Klicker was formerly sales and development manager of the company's rare earths and thorium div.

David W. Miller has been appointed director of operations research and statistical analysis for Calkin & Bayley Inc., industrial consultants, New York City.

Ira K. Hearn, Jr., previously chief industrial engineer of Kennecott Copper Corp.'s western mining divs., was recently promoted to assistant general manager of the Corp.'s Utah Copper div.

J. F. Collins was recently appointed assistant manager of the Pittsburgh region of Electro Metallurgical Co., a div. of Union Carbide Corp.

A. S. Cohan has left the employ of J. M. Mathes Inc., where he was engaged in public relations, and is now serving with Scientific Design Inc. Cohan is a former manager of AIME publications.

J. M. Stapleton, assistant to vice-president—iron production, United States Steel Corp., Pittsburgh, was recently awarded the American Iron and Steel Institute Medal. He won the award for the excellence of his paper *Development of Controlled Air Distribution for the Blast Furnace.*

The American Iron and Steel Institute also honored two other authors of technical papers. **John R. Hunt,** chairman of operating committees, Tennessee Coal and Iron div., United States Steel Corp., Fairfield, Ala., won the *Regional Technical Meeting Award* in the field of operation, for his paper, *Furnace Lines, Operating Methods and Theory of Southern and Northern Blast Furnace Practice.*

J. G. Sibakin, metallurgist, development and special duties div., The Steel Co. of Canada Ltd., Hamilton, Ontario, received the *Regional Technical Award* from AISI for the best paper in the field of research, entitled *The Development of Optimum Ingot Sizes for Flat Rolled Products.*

Frank R. Milliken has been appointed executive vice-president of Kennecott Copper Corp. He was also elected to the Board of Directors of the company. Milliken had previously served as vice president in charge of the company's mining operations.

Adolph E. Palty, formerly affiliated with the Thomson Laboratory of General Electric Co., Lynn, Mass., recently joined Kelsey-Hayes Co., as supervisor, alloy development and evaluation, of the Utica Metals div.

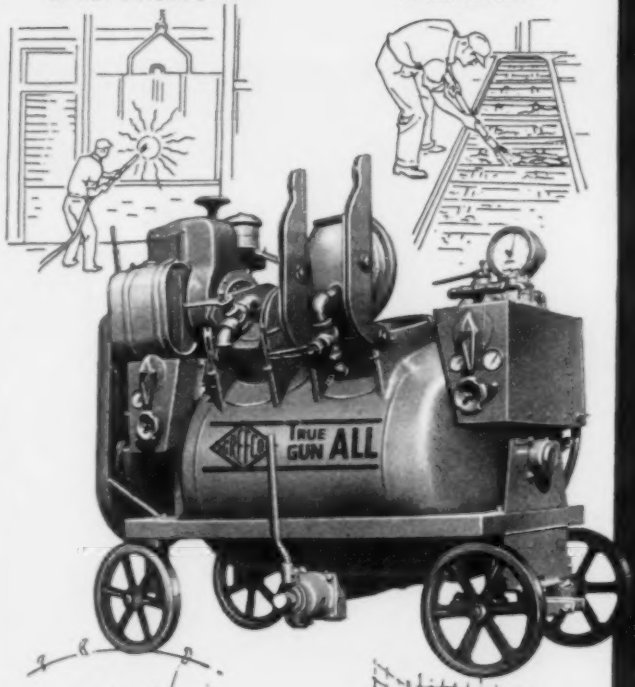
Robert B. Sosman, professor of ceramics, Rutgers University, New Brunswick, N. J., recently received the *Trinks Award*, highest honor of the industrial heating industry, for his pioneering research in silica, steel-making refractories and pyrometry. The presentation was made to him at the annual banquet sponsored by the Trinks Industrial Heating Award Committee in Pittsburgh. Sosman was *Howe Memorial Lecturer* for AIME in 1948.

Gerald L. Owens was recently promoted to vice-president in charge of operations for Great Lakes Steel Corp.'s down-river plants. He was formerly assistant general plant superintendent. Owens has been succeeded in that position by **James G. Smith,** previously manager of primary production.

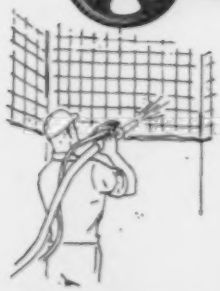
(Continued on page 558)

IN HOT PATCHING . . .

IN CONVEYING . . .



IN VESSEL AND STACK LININGS . . .



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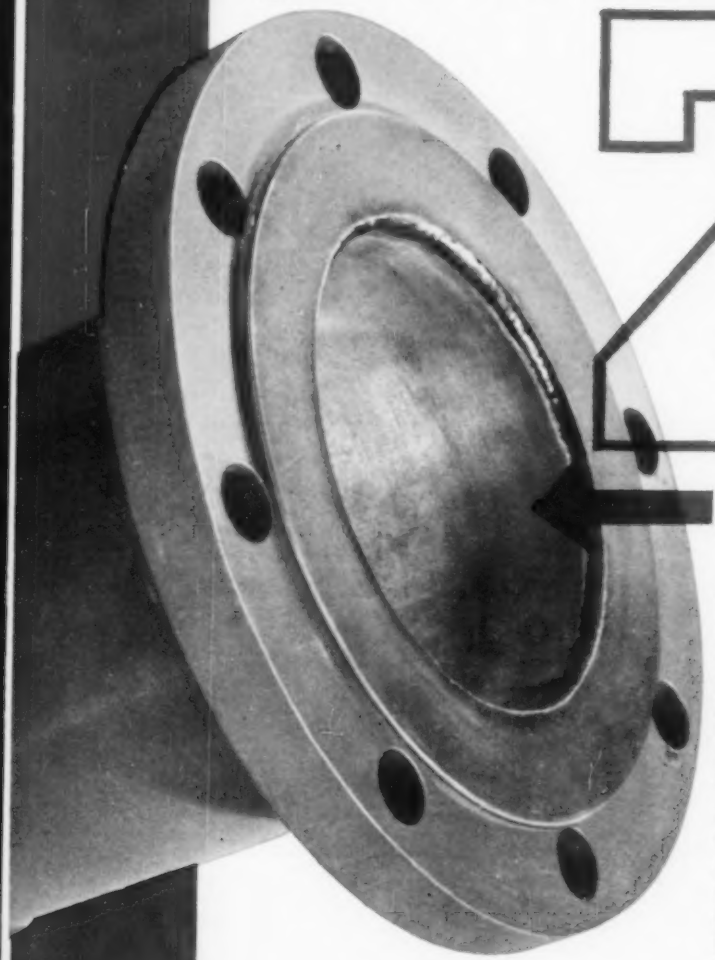

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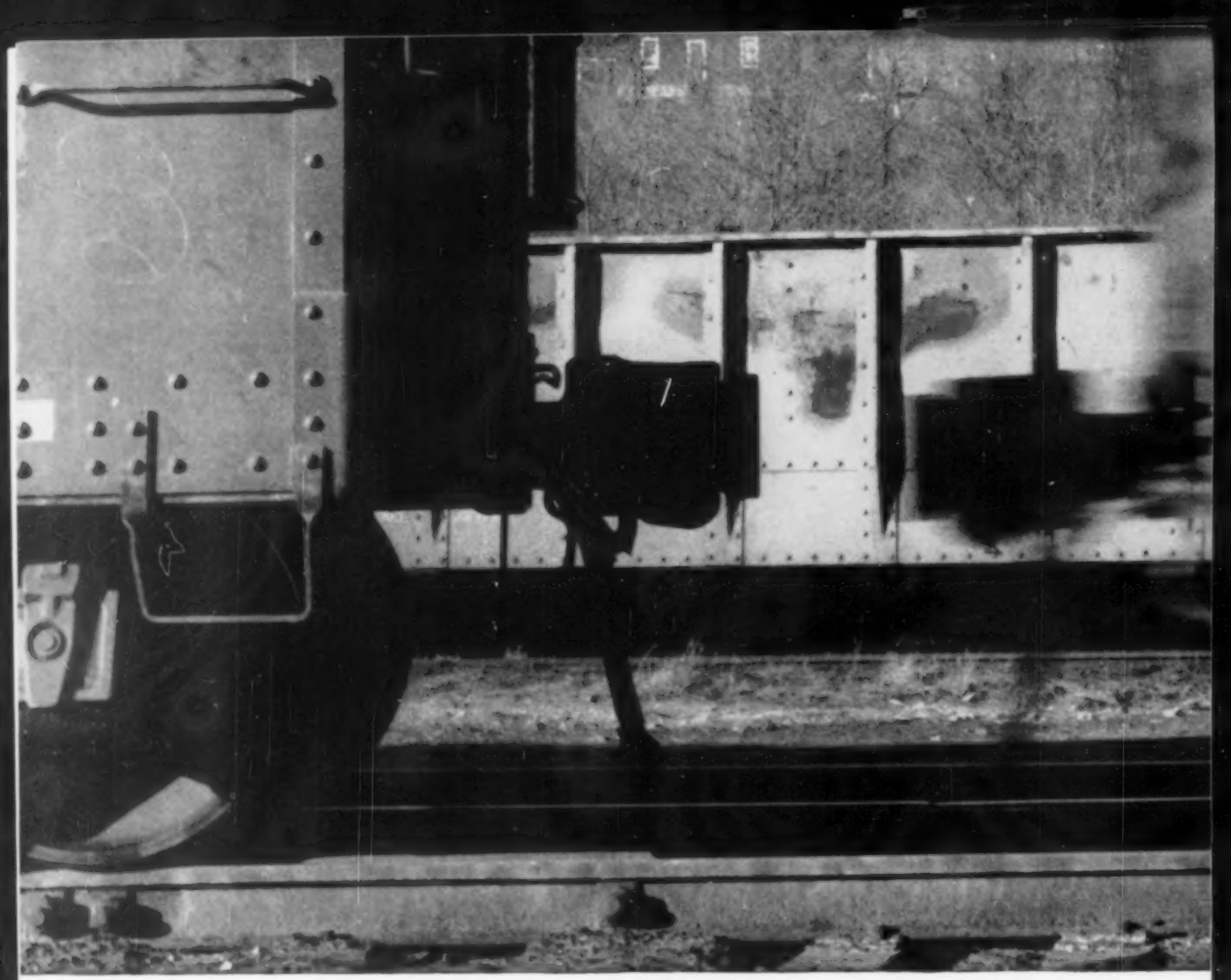


Impact resistance—The image of impact can take many forms. To a train-conscious youngster, impact might be the crash-coupling of freight cars. To the contour miner, impact is a mammoth dipper smashing into frozen highwall. To the ordnance man, impact is a shell striking armor plate. Whatever the image, impact implies one thing—toughness.

Toughness is the ability to absorb energy—to "give" under a shock load without fracturing. This property—toughness—in steel, more than in any other material, has been vital to the building of the modern world. Steel's ubiquitous role, however, belies the complexity of toughness. Because just as there are many kinds of steel, so there are many degrees of toughness, and a given steel's toughness is shaped by the admixture of its composition, manufacture and fabrication.

The design engineer, if he is to do his job well, must know his toughness in order to select the right steel for the job. He must know something of how toughness is achieved, because this often can result in using less expensive steels. The geometry of a part or structure is also important to its toughness, and here the designer reigns supreme.

In steelmaking, toughness and strength are determined by composition and manufacturing steps. Often, as is the case with USS* "T-1" Constructional Alloy Steel, a very high level of strength and toughness is obtained through selection of alloying elements and by proper heat treatment. The steelmaker can help you obtain the best combination of strength and toughness along with other desirable properties like weldability, corrosion resistance, formability and wear resistance. He can also recommend post-fabrication heat-treating practice where it is required to develop mechanical properties or relieve stress in fabricated assemblies.

Clearly, toughness is complex. But for any application, there is one best steel no matter what combination of properties you need. You are almost certain to find that steel among the great family of USS Design Steels: Carbon, High Strength, Alloy and Stainless. Our experience is yours for the asking. Write United States Steel, 525 William Penn Place, Pittsburgh 30, Pa. You'll find our nearest representative in the Yellow Pages listed under United States Steel.

United States Steel Corporation • American Steel & Wire • Columbia-Geneva Steel • National Tube
Tennessee Coal & Iron • United States Steel Supply • United States Steel Export Company

USS *TRADEMARK

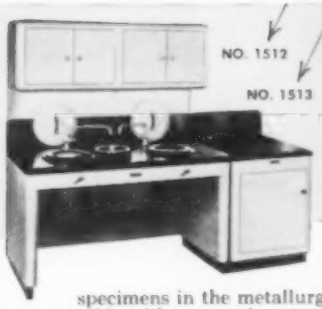
United States Steel

STEELS FOR DESIGN

Lower Left—Problem: Design dump cars for tunnel excavations to remove rock. Must have high impact resistance, plus corrosion resistance to withstand alternate wetting and drying. Solution: Build cars from USS COR-TEN* High Strength Steel. Pay-off: Cars take minimum maintenance, have been in continual service for six years, and are still in excellent condition.

Lower Middle—Problem: Design a 60 cu. yd. shovel that could take the terrific abuse of all-weather overburden removal. Solution: Bucket, bail, dipper stick and crowd rack built entirely of welded USS "T-1"* Steel, a constructional alloy steel having exceptional toughness at below zero temperature and which can be field-welded and flame-cut. Pay-off: Outstanding performance in 7-day-a-week, 24-hour-a-day service with minimum maintenance.

Lower Right— Problem: Design a tank to hold the liquid equivalent of 10 million cubic feet of oxygen at 300°F. below zero. Solution: Tank was designed with impact-resistant austenitic USS Stainless Steel. Pay-off: Tank can withstand sudden changes of pressure, temperature changes and volume at low temperatures that would shatter other materials.



BUEHLER POLISHING DESK

...with matching storage cabinet...

For maximum efficiency in the production of specimens in the metallurgical laboratory the Buehler cabinet type polishing table with companion storage cabinets represents the latest modern development of this type of equipment.

The convenience of this streamlined polishing equipment saves time and encourages the operator to produce the highest quality of polished sample.

Item No. 1511 is a two-unit polishing table with Formica top approximately 60" long x 27" deep by 30" high to table top. Two 12" swing spouts, drain, 8" diameter wash bowl plumbing and wiring.

Recommended accessories to complete an efficient set up for maximum convenience are: No. 1512 storage cabinet with recessed light and No. 1513 supporting panel for installation above polishing desk. Or, No. 1514 floor model storage cabinet. Both these cabinets can be used together to advantage in most laboratories.

The Formica top and back on the table and cabinet is installed with a smooth Formica edge that eliminates all metal rims that may form pockets for water and dirt. Covers are held in place on the back by magnetic holders. The large 8" wash bowl is a new feature that enables the operator to use both hands in washing specimens.

All metal construction finished in hammer tone grey makes a very attractive appearance. Prompt delivery can be made on these new items.

The Buehler Line of Specimen Preparation Equipment Includes . . . Cut-Off Machines • Specimen Mount Presses • Power Grinders • Emery Paper Grinders • Hand Grinders • Belt Surfacers • Mechanical and Electro Polishers • Polishing Cloths • Polishing Abrasives

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2120 Greenwood Avenue, Evanston, Illinois

Personals

(Continued from page 553)

Edward A. Vistica is now associated with the western div. of Eastern States Petroleum & Chemical Corp., Houston, Texas.

Norman R. Alston, formerly with Braden Copper Co., is now serving as assistant dept. head for Phelps Dodge Refining Corp.

Carroll Copps was recently appointed as vice-president of the new chemical div. of Olin Mathieson Corp. Copps comes to Olin Mathieson from Atlas Powder Co. where he was senior vice-president.

Two officials of Kennecott Copper Corp.'s Ray Mines div. have been named officers in the Eastern Chapter, Arizona Society of Professional Engineers, for 1958-59. **Harold W. Bishop,** chief engineer for the Ray mine has been named president of the Eastern Chapter, and **Robert Winkle,** pit maintenance foreman, Ray Mines, was named secretary-treasurer of the Eastern Chapter.

L. L. Farrall, previously vice-president operations for Crucible Steel Co. of America has been elected executive vice-president of the company, and **J. D. Dickerson,** formerly manager of production for Crucible Steel, was appointed vice president —operations for the company.

Robert H. Read has been named supervisor of powder metallurgy research at Armour Research Foundation of Illinois Institute of Technology, Chicago. He had been serving as assistant supervisor of the powder metallurgy section.

William D. Robertson was recently appointed chairman of the Dept. of Metallurgy at Yale University, succeeding professor Arthur Phillips who is on leave of absence preceding his retirement in June 1959.

Clarence L. Altenburger, Detroit, was recently appointed as technical assistant to the president of Great Lakes Steel Corp. In this new position he is directing product development and research groups.

Edwin C. Sponberg, Hibbing, Minn., superintendent of the Scranton iron mine, Mesabi range, has retired, rounding out 33 years with Pickands Mather & Co.

W. L. Harbrecht retired on Mar. 31, 1958 after 38 years employment with the Electro Metallurgical Co., Niagara Falls, N. Y. in research and development work.

Thor N. Rodin, presently employed by du Pont de Nemours Co. Inc., has been appointed associate professor of engineering physics at Cornell University, Ithaca, N. Y., effective August 15th.

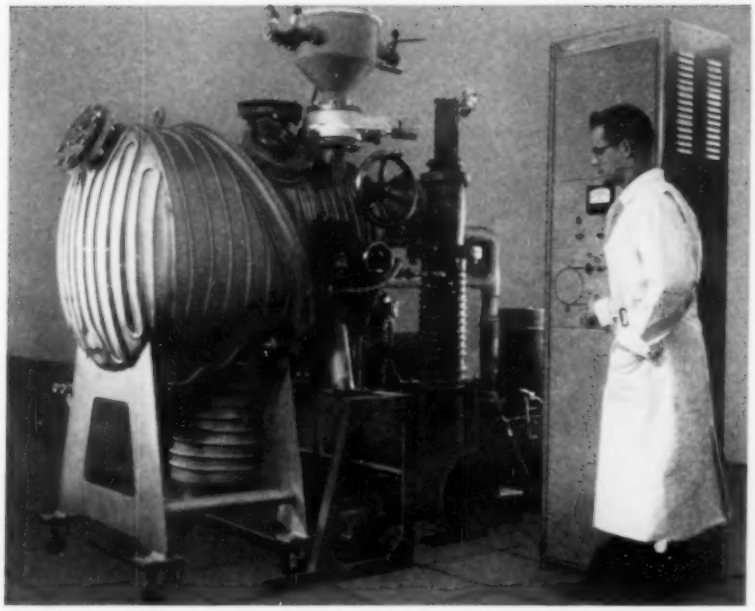
William B. Jacobsen has been promoted to works manager of the Lemont Mfg. Corp.'s new steel mill subsidiary being built by Ceco Steel Products Corp. near Lemont, Ill. Until the mill is constructed, Jacobsen will be headquartered at the Ceco general offices, Chicago.

Carpenter Steel Co., Reading, Pa., recently appointed **W. Kent Kise, Jr.,** as metallurgist in the special alloys development group. Prior to this position, Kise was chief engineer of the Electro-Plastic Corp., Ft. Lauderdale, Fla.

Arnold P. Litman, formerly a metallurgist with Black, Sivalls & Bryson Inc. in the nuclear div., is now affiliated with Oak Ridge National Laboratory, Union Carbide Nuclear Co., Div. of Union Carbide Corp.

The four delegates who represented the United States on Technical Committee 26—Copper and Copper Alloys—of the International Organization for Standardization (ISO), meeting in Harrogate, England, were: **L. H. Adam,** Franklin Arsenal, U. S. Army Ordnance, Philadelphia; **A. E. Beck,** American Metal Co. Ltd., New York; **R. S. Pratt,** chief plant metallurgist, Bridgeport Brass Co., Bridgeport, Conn.; and **J. S. Smart,** research dept., American Smelting and Refining Co., South Plainfield, N. J.

(Continued on page 626)



Process observation, alloy additions, pouring, temperature and process readings, high frequency control, valve sequencing—all focus around one center of operation.

For precision casting

a high-vacuum furnace for lab and pilot plant

CEC's 5 to 50 pound melting and casting furnace offers:

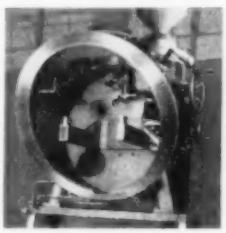
Three-way casting: Melts of 5, 12, 17, 30, or 50 pounds can be cast in single or multiple molds—or (with adaptation) centrifugally.

Ease of materials handling: All parts of the furnace interior are within arm's reach. The oblique angle flange connecting the stainless steel chamber sections provides unusual vertical clearance for removing molds directly. A deep water-cooled mold well provides 33" under the crucible lip for pouring bar-type ingots. Electric feedthroughs are provided for mold heating.

Complete controls: The basic furnace includes a manual bridge-breaker, a feeder and alloy cup mechanism, and a nonfogging sight tube for optical pyrometry. Pneumatic line valves are interlocked and controlled from central panel for safe, sure operation. It's easy to add a sampler, thermocouple, and equipment for semi-continuous operation.

Ample pumping: A 2-stage diffusion-ejector pump quickly brings the compact system to the low micron pressure range, with ample reserve capacity to handle gas loads generated by alloy additions, deoxidation, and pouring.

Write for illustrated Bulletin 4-30, which lists complete specifications, accessories, and design features of this remarkably versatile furnace.



Interior view of compact furnace shows alloy addition devices and crucible trunions.

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BOOKS

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Technical Report Writings, by James W. Souther, *John Wiley & Sons Inc.*, 70 pp., $2.95 paper bound.—The author, an assistant dean of engineering at the University of Washington, has aimed this illustrated textbook and reference manual to provide information about how industrial reports are actually written—centering on the writing process. The author stresses the relation between the industrial function of the report and the final form it must take. •

Rapid Analysis of Nonferrous Metals and Alloys, by George Norwitz, *Chemical Publishing Co. Inc.*, 212 Fifth Ave., New York 10, N. Y., 112 pp., $4.25, 1957.—This book differs from other available books on metal analysis in that there is an increased reliance on sequence procedures; mathematical correction factors are used to advantage to eliminate lengthy separations; colorimetric procedues are extensively employed; and great use is made of perchloric acid, especially for destroying organic matter. Although the methods discussed in the book will save much time to the busy analytical chemist, speed has not been overemphasized. In addition, the short cuts, reliability, accuracy, and simplicity of this book will make it invaluable not only to trained chemists, but also to routine operators.

english-french and french-english Technical Dictionary, by F. Cusset, *Chemical Publishing Co. Inc.*, 212 Fifth Ave., New York 10, N. Y., 663 pp., $8.00, 1957.—This completely revised and enlarged edition of a popular dictionary will be welcome to engineers, chemists, metallurgists, mineralogists, librarians, translators, interpreters, abstractors, students, and in general to all those who have to read or refer to French technical texts. Diverse technical fields are adequately covered and the French equivalents of English technical terms and vice versa are chosen with great care and competence. This edition contains many revisions and corrections and includes hundreds of new words which were either inadvertently omitted from the first edition or concern recent technical and scientific developments which took place since the first publication.

(Continued on page 565)

Smashing scrap since 1953 . . . this 48" diameter, 16,770-lb. Ni-Hard drop ball is still going strong. Pays maximum return per dollar invested. High hardness helps lengthen its life. In addition, it is tougher than this hardness indicates. That's why it withstands the shock of jolts against scrap. Produced by United Engineering & Foundry Co., Pittsburgh, Pa.

Ni-Hard ball outlasts others by 3 to 1 ...breaks 27,000 tons of scrap and still on job

A Ni-Hard* drop ball earns you money because its resistance to abrasion greatly increases its life. Look at this one, for example . . . on an open hearth scrap drop at United States Steel Corporation's Youngstown District Works.

The ball looks battered, with one side slightly flattened out . . . but it should be after the service it has already given:

This Ni-Hard ball has broken up some 25 tons of scrap a day, seven days a week for more than three years.

Balls made of other materials averaged only 13½ months in the same service. Yet after 40 months the Ni-Hard ball is still in use. As a result of its unmatched resistance to abrasion, it still retains its working weight.

You'll profit by using a ball that stays hefty longer as it breaks up your scrap. So specify your next drop ball in Ni-Hard nickel-chromium white iron. A list of authorized producers is yours for the asking. Write for it now.

*Registered Trademark

Ni-Hard drop balls come in various sizes, and applications include fragmentation in reclaiming steel scrap from slag, breaking up cast iron scrap, powdering rock and the like. These drop balls were cast by United Engineering & Foundry Company.

INCO TRADE MARK **THE INTERNATIONAL NICKEL COMPANY, INC.** 67 Wall Street New York 5, N.Y.

Egypt's first pig iron production

Egypt . . . now on the road toward becoming the first integrated steel producer in the Middle East . . . recently blew its initial blast furnace into production at Helouan in the suburbs of Cairo. It has an annual capacity of 130,000 metric tons of pig iron; a second blast furnace of similar capacity will be blown-in later this year. Both will use imported coke to smelt ores from the vast deposits in the Aswan region. The plant, which is being built by a west German group headed by Demag, will make use of converters and electric-arc furnaces for producing steel to be rolled into bars, sections, plates, and rails.

Hot-blast cupola—LD combination in America

Foundations for the first hot-blast cupola—LD converter combination on this side of the Atlantic are being laid at Acme Steel Co. Scheduled to be in operation early in 1959, the plant will make use of scrap for the production of hot metal, which will be blown into steel in two 50-ton capacity LD converters. The unit is patterned after the plant of Gussstahlwerk Witten in Germany which is described on page 599 of this issue of JOURNAL OF METALS.

Oxygen for open hearths at Granite City

A 60-million-cu-ft-per-month oxygen plant . . . built by Air Products, Inc. . . . has been brought into production at Granite City Steel Co. to feed open-hearth furnaces with oxygen in order to increase flame temperature and accelerate the refining period. Open hearths are already fired by fuel oil that is atomized by high-pressure natural gas (see JOURNAL OF METALS, p. 272, April, 1958), and the introduction of oxygen will further accelerate combustion through the furnace burners. The decarburization period will be reduced by jetting oxygen on the bath from a lance extended from the roof.

Sixth US primary aluminum producer

On the Columbia River near Portland, Ore., the 54,000-ton aluminum reduction works of Harvey Aluminum is starting operation, thereby bringing the number of US primary producers to six and the total US capacity to 2,080,000 tons per year. Reduction facilities consist of 240 pots, housed in four separate buildings. The aluminum pots were designed, engineered, and built by Harvey Aluminum at its Torrance, Calif., plant.

Domestic sources of beryllium extended

Discoveries in the Crystal Mountain and Storm Mountain districts of Colorado are reported to have assured America of its first substantial supplies of beryllium ores. Some 400 tons of ore are now being offered daily from this source. At the same time, the US Bureau of Mines is cataloging, classifying, and evaluating all known occurrences of beryl, and it will also reexamine every pegmatite area. The Bureau of Mines will seek improved methods for the recovery of beryl minerals and the processing of beryl concentrates. Recovery practices now employed generally include flotation, but because of the varied mineral associations almost every deposit requires a different technique.

CALCIUM-SILICON
CALCIUM-MANGANESE-SILICON

NO CURE-ALL BUT...

. . . they have proved to be highly versatile and are widely used in quality wrought and cast steel and high strength cast iron.

Many producers use calcium silicon to make cleaner wrought steel. Its primary function is to deoxidize and degasify — the low melting deoxidation products formed readily free themselves from the metal. Particularly effective in controlling type and distribution of inclusions in bearing and aircraft quality steels, calcium silicon also improves hot workability of stainless steel.

In steel castings calcium silicon improves physical properties by minimizing the tendency to form undesirable Type II inclusions. (Some foundrymen prefer to use calcium-manganese-silicon for this purpose — this more dilute alloy is less reactive and forms even lower melting point deoxidation products.)

For high strength iron castings calcium silicon is an effective inoculant. It is frequently used as a ladle addition to low carbon equivalent iron. For certain ductile irons specifying low silicon content, calcium silicon is sometimes used as the inoculant due to its lower silicon content.

We maintain adequate stocks of lump and crushed sizes for furnace and ladle additions. Your order will be shipped promptly.

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EDITORIAL

Liberal Arts and the Space Age

Adapted from an address by Dr. Frank H. Driggs,
President, Fansteel Metallurgical Corp.

Delivered at the Baker University Centennial Commencement, June 2, 1958.

EVENTS of the past three or four decades have brought our educational systems into sharp focus. A great hue and cry has been raised from various sections and groups throughout the country for their complete overhaul and revision. Charges and countercharges are made even in the halls of Congress. As in all periods of great mental stress, we are very apt to make fundamental and costly errors during our endeavors to rectify certain real or imaginary deficiencies in present educational systems. I would like to establish three points in regard to this subject.

The first point is *that a liberal education is an essential base for any individual to gain the most from life.* Let us analyze just what we mean by a liberal education. If we reduce the term, liberal education, to the smallest number of divisions or parts, these might be listed as follows.

1. A sense of values based on studies of philosophy, religion, ethics, history, and human experience.
2. The possession of basic skills and abilities, including mastery of the scientific method, understanding of people and how to work with them, ability to concentrate, and ability to organize.
3. A selected knowledge of certain facts and relationships.
4. Satisfaction, joy or well-being experienced in exercising the above talents and the will to apply ones self to the task.

If a liberal education can be defined as consisting of the above elements, it becomes apparent that a liberal arts course is almost essential in order to supply that particular type of educational background. Naturally it must include studies of mathematics, history, religion, philosophy, and the natural sciences. However, the term liberal arts implies not only a knowledge of these subjects, but it also includes the ability to use them. Thus, the liberal arts are the most useful of all arts because they help to fulfill the highest of all human purpose, the perfection of man as an individual.

The second point I propose is *that a liberal education is the most essential ingredient or base for all educational programs designed to meet the problem of this technical age.* This statement, at first glance, appears to be of the most rabid and reactionary nature and a complete denial of the present trends in education. You may well ask, "How can we prepare our youth for the highly specialized demands of the future while we calmly allow them to waste precious years in generalizing upon a myriad of subjects not essential for their specialized assignments?" My first answer would be that if we are required to develop a corps of accountants whose reading is confined to the balance sheet, a corp of chemists whose outlook on life is through the walls of a test tube, or a group of physicists who admire a beautiful waterfall because of its potential energy content, then I sincerely question the advisability of its survival.

Sputnik I was hardly in orbit when there arose a hue and cry throughout the country that we develop institutions which would mass-produce scientists and engineers. A veritable flood of comments, papers, articles, studies and conferences have been held to determine what should be done to improve or readjust our educational systems to meet the growing threat of a communist-controlled technical world. Some remarks during these conferences would lead us to believe that our colleges and universities should be remolded overnight. The atomic physicists, who had held unquestioned sway in the scientific field since 1942, were summarily dethroned and the rocket engineers were crowned in their stead.

However, as time passes the age of reason seems to be reasserting itself again. What were the true findings and conclusions of these study groups and committees? Exactly what you or any sane person would suspect after serious and sober contemplation namely, that education in the social sciences and the liberal arts must not be sacrificed in favor of more science subjects. Their recommendations in a nutshell were, "drop nothing, just add." What do these terse phrases really imply? They simply mean that we need first and primarily a sound, well-balanced, and well-educated mind upon which to build the specalized train-

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ing and education for the critical assignments of the individual in his later life. I contend that any individual with a basic liberal education can, after some study, easily comprehend the fundamentals of any science, art, philosophy, or religion, if he has really gained from his basic liberal education.

However, a broad liberal education is not only desirable in our democratic civilization, but it is also a moral obligation that rests upon every individual who is in a position to participate in such an education program. The duties of citizenship, national and local politics, and the moral and religious welfare of the community rests upon every citizen, be he scientist, musician, minister, or common laborer. Specialization should constitute no convenient retreat from the community obligations of every member of the human race.

I also believe that another mistaken concept has gained considerable credence in this age of the adoration of the expert; namely, that our recent crop of experts, be they scientists, political scientists, or other specialists, have through their own efforts alone, made these terrific advances in our modern civilization.

Availability of materials and equipment, and the discovery of uranium isotope 235, made possible the development of atomic energy which had been visualized and pointed out by Einstein and others many decades ago. I well remember hearing in a physics class in 1916 the theory of an artificial satellite circling the earth with the speed of 18,000 mph. This was, I believe, well in advance of the birthdate of Von Braun and most of our present rocket scientists. The availability of miniaturized electrical controls, high energy fuels, and high-temperature resistant metals have contributed in a large measure to the success of scientists in accomplishing this feat.

The average age of graduating classes throughout the US this spring is probably 22, 23, or 24 years. In ten years, possibly a few will have reached the stage of full productive capacity. In twenty years, and an average age of 42 to 44 years, it is more likely that a majority of this group will have reached the period of their maximum productive effort. However, in thirty years and an average age of 52 to 54, a very large number of this class will, in all probability, just be attaining the age of maximum productivity. In the face of these statistics can we afford to weaken the educational foundations of our university graduates for the purpose of saving one or two short years at most? In this advanced age, we can well afford to spend the additional years on basic education before any attempt at specialization begins. Therefore, I say again that the terse statement of findings of the group who were studying our present educational programs, "drop nothing—just add" represented the most constructive and sound advice that could possibly be enunciated in these critical times. Our future will be more safely assured, if our rocket experts are also articulate, if our atomic physicists have a deep understanding human nature, and if our lawyers and ministers also have a basic understanding of the scientific method. In other words, may a liberal education be the common denominator and identification mark for our leaders of the future.

I come now to the last point, and that which I consider the most important, because I feel that this will largely determine, not only the future of our Nation, but possibly the future of civilization itself. It is, *that individualism, self-reliance, and independent thought are the best sources of social and technological progress with which to combat the growing threats of collectivism.*

Man was endowed by his creator with human dignity and possessing certain inalienable rights—rights which all people, all nations, and all the world must respect. This principle must be maintained, if we are to preserve all that is implied by the term, "a free society." As our present industrial age, technological age, space age, or even inter-stellar age develops, every individual finds himself more closely oriented, more confined in his daily activities, and classified into smaller and narrower limits of endeavor. In turn, he finds himself becoming a member of a closely knit, well-organized group. This group, or these groups, naturally are inclined to protect only those institutions and principles which are of direct interest and benefit to them.

The Bill of Rights is used not as a document to protect all individuals and all peoples. Instead, the separate amendments are extracted, flaunted, and used for this or that particular group to its own selfish advantage. For example, newspapers, periodicals, radio, and television groups are extremely interested in maintaining the provisions of the First Amendment, freedom of the press. On the other hand; they give indifferent support to the provisions of the Fifth Amendment. Eccentric religious sects are interested in freedom of religion, not particularly in freedom of the press. Communists, or other subversive groups, are enthusiastic concerning the protection afforded by the Fifth Amendment, while at the same time it is very obvious that most of the remainder of the Bill of Rights is not a part of their ideology. This situation poses a very serious and frightening question—who is interested in the Bill of Rights as a whole? It has been intimated in some of the highest quarters of our Land that considerable doubt exists as to whether the Bill could actually be adopted today. This, if true, is an alarming commentary an the status of our social and political ideas of today. The Bill of Rights guarantees all forms of individual freedom and was designed to protect every citizen and every individual against any and all organized units, be it government, pressure groups, industrial corporations, labor unions, or dominant political parties. It is not simply to communism, to fascism, or to any other type of "ism" that we are in danger of losing our individual liberties. It is rather the remorseless tendency of our modern technical, industrial, and highly specialized systems of developing large pressure groups which tend to restrict the natural freedom of every individual and to bury him and his individuality in a great cauldron of humanity.

Bureaucracy is not confined today to government. It exists and tends to grow everywhere and in every walk of life as it becomes more complex. Even the farmer, that primary and most basic of individual self-sufficiency, finds himself being overwhelmed and incorporated in a bureaucratic pressure group, sometimes against his natural and hereditary tendencies. Every individual today is faced with this dilemma—that he must join a group to obtain freedom, justice, and his rightful place in society, and then finds to his dismay that what he hoped to find *through* his union or group, he cannot find *in* it. No form of society which is willing to sacrifice the rights of the individual for the temporary advantage of a group can long hold up its head as the answer to man's existence on this earth. The greatest humanitarian of all history once said, "Inasmuch as you do it unto the least of these, you do it also unto me." What greater appreciation for every living human could be shown by this leader of all men whose soundness and beauty of teachings have never been questioned.

In closing, I would like to paraphrase some statements made at the University of Chicago shortly after the launching of the first satellite by the Russians. On December 2, 1942, in this country, man entered the Atomic Age. On October 5, 1957, somewhere in Russia, he entered the Age of Space. These events brought man to one of the great benchmarks of his existence. What now should be the future of western civilization and the role of the colleges and universities? The answer is neither exciting nor startling. We should continue to nurture the inner space—the minds of men wherein lies the key to the future.

Books

(Continued from page 559)

Grey Iron Castings Handbook, edited by Charles F. Walton, *Grey Iron Founders' Society Inc.*, Cleveland, 620 pp., $10.00, 1958.—This comprehensive guide book features in one volume, information on how to successfully and economically design, purchase, and use grey, ductile, white and high alloy iron castings. Included are sections on: the design of grey iron castings; heat treatment; welding, joining and cutting; machining and grinding; metallic and nonmetallic coatings; and a review of the history of grey iron. The handbook contains 411 illustrations and graphs, 64 tables and extensive bibliographies after each chapter, as well as a glossary of foundry terms and an index.

Review Series summarizes and evaluates current developments in power reactor technology. Issued quarterly, it reports both on research and development results applicable to reactors generally and on progress made with specific reactor types. Each issue will vary in topical content. However from time to time the following areas will be reviewed as developments warrant: applications, performance and evaluations, heat transfer, reactor kinetics and control, safeguards and containment, shielding, reactor components, fuel handling, materials and radiation effects, pressurized water reactors, boiling water reactors, liquid metal-cooled reactors, gas-cooled reactors, aqueous homogeneous reactors, liquid metal-fueled reactors, other power reactor types, and reactors for research, testing, and other applications. **Power Reactor Technology** may be purchased by subscription (domestic, $2.00; foreign, $2.50) or by individual issue (55c) from the *Superintendent of Documents*.

The Economics Of Nuclear Power including Administration & Law, *Pergamon Press Inc.*, 122 E. 55th St., New York 22, N.Y., $17.00, 1957—This book which is a series of ten covering all aspects of nuclear energy, provides a comprehensive and detailed review of the various economic problems involved, including the relationship between the nuclear power and transport facilities, and the amount of capital available and required. Included are detailed studies and estimates of various national and global requirements, which take into account such factors as the absence and exhaustion of conventional sources of fuel and power. Besides these overall considerations, the examines the available data on such questions as the new type of cost indices concerned with reactor operation, the balance between fuel and capital costs, and the importance of breeder reactors in relation to nuclear fuel resources. The administrative and legal aspects of protection from radiation, compensation, insurance, and the transport and the disposal of radioactive wastes are also dealt with. •

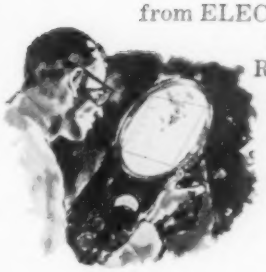
Atomic Structure and the Strength of Metals, by N. F. Mott, *Pergamon Press Inc.*, 122 E. 55th St., New York 22, N.Y., $2.75, 1957—In easily comprehensible terms and illustrations this book presents the structures of atoms, shows how metals are built of atoms, and how the atoms within the metals behave when the metal is bent or made to stretch under a strain. Although primarily prepared for university students of the humanities, it will make stimulating and informative reading for every enquiring member of the general public. •

An Introduction To Reactor Physics, International series of Monographs on Nuclear Energy, Division X, Volume I, by D. J. Littler and J. F. Raffle, *Pergamon Press Inc.*, 122 E. 55th St., New York 22, N.Y., $4.50, 1957—Published for the United Kingdom Atomic Energy Authority, this up-to-date Second Edition forms an excellent introduction to the principles of reactor physics. The treatment has been kept as simple as possible and deals with nuclear physics from a general theoretical viewpoint. Little mathematical knowledge is required by the reader. •

Handbuch Der Sonderstahlkunde, Third Edition, by Edward Houdremont, *Springer-Verlag*, Berlin, Germany, 1538 pp., 2 vols., DM 220, 1956—This reference work on alloy steels, brings together the relevant information contained in hundreds of articles, papers, and reports. Following an opening chapter on the properties and characteristics of pure iron, volume I continues with extensive sections on carbon steels, including full coverage of their heat treatment, and on manganese, nickel, and chromium steels. Volume II deals with tungsten, molybdenum, vanadium cobalts and silicon as alloying elements, and with the effect on steel of aluminum, copper, titanium, phosporus, sulphur, various gases, and some of the rarer elements. In each major section the author considers general characteristics, tool steel alloys, structural steel alloys, and the influence of the particular element on the physical and chemical properties of the steel, and its manufacture and working. Metallurgical aspects are stressed throughout, with full illustration by means of constitution diagrams, microphotographs, and hundreds of graphs. In addition, data tables present in concise form the information contained in the footnote references for which an author index is supplied.

(Continued on page 566)

from ELECTROMET Metals Research



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Books

(Continued from page 565)

Thermal Properties of Ceramics, Engineering Research Bulletin No. 40, by Edward J. Smoke and John H. Koenig, *Bureau of Engineering Research, College of Engineering, Rutgers University,* New Brunswick, N.J., 53 pp., 75¢, 1958—This is a report from the New Jersey Ceramic Research Station of the Rutgers Bureau of Engineering Research. It describes the findings in some phases of the extensive research in ceramic dielectronics which has been carried out there over the past twelve years. The subject matter of the Bulletin is divided into five sections: melting and safe operating temperatures of ceramic materials, thermal conductivity of ceramics, thermal expansion of ceramics, thermal endurance of dense ceramics and thermal conditioning. Each section has its own bibliography. Seventeen illustrations enrich the text.

Lattice Inhomogeneities and Substructures In Crystalline Materials, Engineering Research Bulletin No. 39, by Sigmund Weissmann, *Bureau of Engineering Research, College of Engineering, Rutgers University,* New Brunswick, N.J., 46 pp., 1956—This bulletin describes the new diffraction methods designed to study the lattice imperfections of single crystals as well as coarse and fine-grained specimens, and discusses the results of their application to some specific problems in metallurgy. The booklet covers description of X-ray methods, X-ray double crystal diffractometer for study of single crystals and coarse-grained materials, application of the X-ray double crystal diffractometer method, and study of lattice imperfections of polycrystalline materials. The bulletin is complete with photos, graphs, and list of references.

The Powder Method in X-ray crystallography, by Lenoid V. Azaroff and Martin J. Burger, *McGraw-Hill Book Co. Inc.*, 342 pp., $8.75, 1958—This book contains a complete exposition of the principles and utilization of the powder method. The discussion is kept on a fundamental plane, and no mathematics beyond simple vector algebra is assumed. All necessary mathematics is included in the simplest and most complete way possible. Detailed examples illustrate virtually all principles, and a complete collection of charts for laboratory use of indexing procedures is included. The contents includes: elementary X-ray diffraction theory, principles of powder photography, relation of spacings to cell geometry, interpretation of powder photographs, reduced cells and their application, the sources of error in measured spacings, and the practice of attaining accuracy. Index and Appendix are included. •

Engineering Materials Handbook, by a staff of specialists, *McGraw-Hill Book Co. Inc.*, 1936 pp., $21.50, 1958.—This new and up-to-date comprehensive reference book considers materials from the viewpoint of engineering structures, machinery, and equipment. Gathered together in this one volume is the kind of information required by anyone concerned with planning design, structure, manufacturing and serviceability. Each of the 43 sections was prepared by one or more specialties. Emphasis is placed on the fabricated forms of materials, their physical and mechanical properties, their adaptations, advantages, limitations, competition with each other, protection against deterioration, and increase in their stability to stand use and abuse. The handbook contains 648 illustrations. •

History of the Iron and Steel Industry, from 450 B.C. to A.D. 1775, by H. R. Schubert, *The Iron and Steel Institute,* 4 Grosvenor Gardens, London, S. W. 1, England, $8.45, 1957.—This long awaited book is the first comprehensive history of British iron and steel making from its earliest appearance in prehistoric times to the introduction of steam power. Written in two parts, the book deals lucidly with many fascinating technical and archaeological problems and is copiously illustrated to make the subject interesting not only to the iron master and engineer, but also to the historian and archaeologist.

Uber Die Aushärtung Von Aluminum-Kupfer-Legierungen, by Herman Franz, *Aluminum Verlag,* Dusseldorf, Germany, 156 pp., $4.80, 1957—A summary of research on the hardening of aluminum copper alloys. Part I is devoted to X-ray, microscopic, mechanical, electrical, magnetic, and colorimetric results of experiments. Part II deals with the thermodynamic energies and kinetics of the hardening process. The bibliography lists 239 references.

U. S. Department of Commerce Publications

Request publications from:
Office of Technical Publications
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PB 121941 *Research on Elevated Temperature Resistant Ceramic Structural Adhesives, Part 2,* by H. G. Lefort, R. M. Spriggs, and D. G. Bennett, University of Illinois for Wright Air Development Center, U. S. Air Force, $2.00, 74 pp., 1957. Vol. 1 of the report, released earlier, is **PB 121659,** same title, $2.50, 99 pp., 1956.

AEC-tr-2941 *Project of a 420 MW Atomic Electric Station,* Committee for Participation of USSR in International Power Assns., 25¢, 22 pp., 1957.

PB 131062 *Preparation of Protective Coatings by Electrophoretic Methods,* by A. C. Werner and others, Vitro Corp. of America for Wright Air Development Center, U. S. Air Force, $1.50, 53 pp., 1957.

PB 111911 *Research and Development on Electrodeposition of New Chromium and Chromium-Alloy Plate,* by L. D. McGraw and others, Battelle Memorial Inst. for Bureau of Aeronautics, U. S. Navy, $2.25, 82 pp., 1952.

PB 131106 *Catalytic Effect of Titanium on the Oxidation Stability of Lubricants,* Watertown Arsenal Laboratories, U. S. Army, 75¢, 28 pp., 1955.

AEC Research Reports Price List No. 28, listing of more than 4500 unclassified research reports, Free, 1957.

PB 121908 *Research on Elevated Temperature Resistant Inorganic Polymer Structural Adhesives: Part 2,* by H. H. Levine, Quantum Inc., for Wright Air Development Center, U. S. Air Force, 75¢, 30 pp., 1956.

PB 121856 *Development of Metal-Bonding Adhesive With Improved Heat Resistance,* by J. M. Black and R. F. Blomquist, Forest Products Laboratory, U. S. Dept. of Agriculture, for Wright Air Development Center, U. S. Air Force, 50¢, 20 pp., 1957.

PB 131046 *Development of Non-Destructive Adhesive Bonds: Part 5,* by J. S. Arnold, Stanford Research Inst. for Wright Air Development Center, U. S. Air Force, $1.75, 62 pp., 1957.

PB 121662 *A Handbook on the Properties of Cold Worked Steels,* by L. J. Ebert, Case Inst. of Technology for Watertown Arsenal Laboratory, U. S. Army, $3.00, 113 pp., 1955.

PB 111917 *Literature Survey on Leaded Steels,* by R. C. Elliott and D. M. Koffman, Watertown Arsenal Laboratory, U. S. Army, $1.00, 38 pp., 1955.

PB 131025 *Interrelation of Fatigue Cracking Damping and Notch Sensitivity* by L. J. Demar, University of Minnesota for Wright Air Development Center, U. S. Air Force, $4.25, 164 pp., 1957.

PB 121795 *An Investigation of Intergranular Oxidation in Stainless Steels and High-Nickel Alloys,* by C. A. Siebert and others, University of Michigan for Wright Air Development Center, U. S. Air Force, $1.50, 53 pp., 1956.

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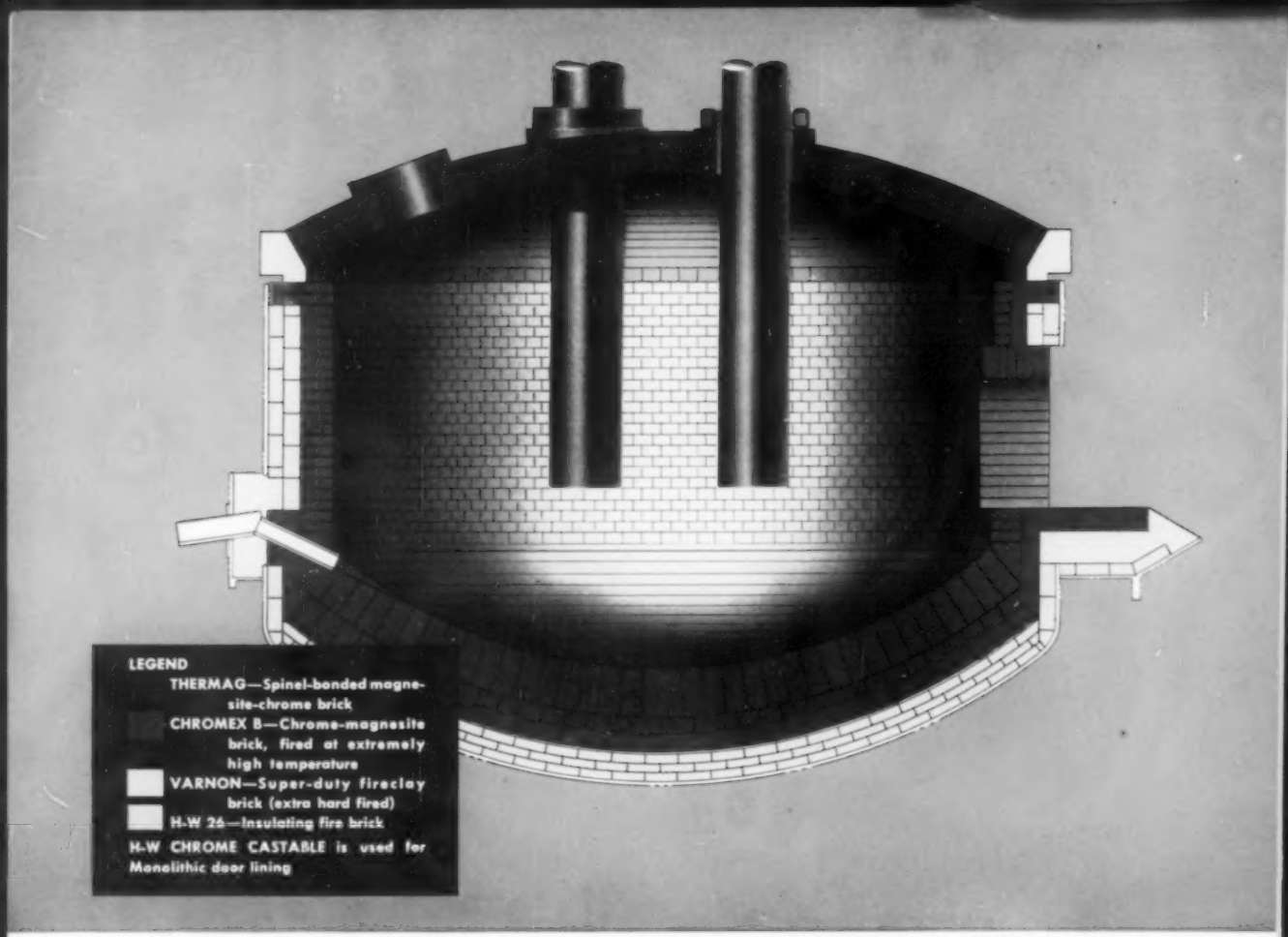
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Exterior view of world's largest electric copper melting furnace (courtesy of ASARCO)

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THE FALL MEETING OF THE METALLURGICAL SOCIETY

Program and Abstracts

General Information

Registration: To minimize confusion on Monday morning, registration facilities will be available on the Mezzanine of the Carter Hotel in Cleveland on Sunday, October 26, from 3:00 until 9:00 pm. If you are in Cleveland on Sunday, please register in advance. The registration fee is $5 to AIME members, $10 to nonmembers, and $1 to nonmember students. The fee includes the abstract booklet as long as the supply lasts. There will be no registration fee for Student Members of AIME nor for those attending the dinner only. Students are requested to register. In addition to the above mentioned advance registration facilities, you may register on the Mezzanine of the Carter Hotel on Monday, Tuesday, and Wednesday from 8:00 am to 4:00 pm, and on Thursday from 9:00 am to 12:00 noon.

Fall Meeting—Three Divisions Represented: This year for the first time the Fall Meeting has a new name—"Fall Meeting of The Metallurgical Society Sponsored by the Institute of Metals Division." In addition to technical sessions arranged by the Institute of Metals Division, sessions have also been planned by the Extractive Metallurgy Division and by the Iron and Steel Division. The technical program this year will involve four simultaneous sessions from Monday morning through Thursday noon.

Institute of Metals Division Sessions: The IMD Semiconductors Committee will hold the first technical session under its sponsorship on Monday morning, October 27. The subject of this session will be a "Symposium on Government-Sponsored Research on Semiconductor Metallurgy." The technical session will be followed by a luncheon which all registrants interested in the subject of Semiconductors are invited to attend.

The IMD Chemistry and Physics of Metals Committee is sponsoring two sessions to be held on Monday morning and Tuesday morning. The first will be a Symposium on "Point Imperfections," and the second, a Symposium on "Effects of Small Dimensions."

The IMD Physical Metallurgy Committee will hold the first technical session under its sponsorship on Monday afternoon with a Symposium on "Effect of Ordering on Mechanical Properties."

The Seventh Annual Titanium Symposium will be held on Tuesday morning and afternoon. At the morning session, a panel discussion will be held on these topics, "Price, Quality, and New Process Prospects for Titanium Sponge, Ingot, and Billet," "Price Trends and Market Analysis of Titanium Products," and "Current and New Uses of Titanium in Missiles, Aircraft, and Aircraft Power Plants." In the afternoon, a panel discussion will be held on "Status and Use of Titanium Abroad," "Review of Department of Defense Sheet Rolling Program," and "New Alloys."

The Annual Symposium on "Nuclear Metallurgy" will be held on Wednesday morning and afternoon. The subject for the Symposium is "Fabrication of Fuel Elements." On Wednesday morning six papers will be given on the subject of "Ceramic Base Elements," and in the afternoon, seven papers on "Metal Base Fuels and Jacket Components."

The IMD Electrical and Magnetic Metals Committee will hold its first technical session with review papers on "Magnetic Methods in Metallurgy," "Physical Metallurgy of Magnetic Materials," and "Applications of Magnetic Materials."

The IMD Refractory Metals Committee, in cooperation with the IMD High-Temperature Alloys Committee, will present three technical sessions on Wednesday morning and afternoon and on Thursday morning. The titles of these three sessions are "Oxidation Protection and Fabrication," "Metallurgy of Columbium and Its Alloys," and "Mechanical Properties and Effect of Interstitials."

The IMD Powder Metallurgy Committee will conduct its annual symposium with papers on high-purity tantalum, molybdenum-nickel dispersion alloys, titanium carbide, and carbonyl iron. An additional feature will be a report on the Third Plansee Seminar held in Reutte/Tyrol, Austria. Following the practice in recent years, powder metallurgists will gather for a general luncheon after conclusion of the technical session. A report will be given on the Geneva Conference on atomic energy. After lunch, there will be a session on "Liquid Phase Sintering."

Twelve sessions of research summaries have been scheduled based on the submission of some 80 research abstracts.

GENERAL INFORMATION

Extractive Metallurgy Division Sessions: The Extractive Metallurgy Division is participating in the Fall Meeting for the first time. Two sessions have been organized by the EMD Physical Chemistry of Extractive Metallurgy Committee and will be held on Tuesday morning and afternoon. The first of these is a Symposium on "Physical Chemistry of Halide Systems," and the second on "New Applications of the Phase Rule in Extractive Metallurgy."

Iron and Steel Division Sessions: The Iron and Steel Division has arranged two sessions to be given on Tuesday morning and afternoon, which will feature reports by U. S. metallurgists who have recently visited iron and steelmaking plants in the Soviet Union.

Authors' and Chairmen's Breakfasts: The breakfast for session chairmen and authors who will present papers on Monday sessions is scheduled at 8:00 am in the Aviation Room, Monday, October 27. For chairmen and authors on Tuesday sessions, the breakfast will be held in the Aviation Room at 7:30 am on Tuesday, October 28. The breakfast in the Aviation Room at 7:30 am on Wednesday, October 29, will be for both Wednesday and Thursday authors and chairmen. The breakfasts will be on a Dutch treat basis, $3.00 per person.

Annual Fall Dinner: The annual fall dinner will be held in the Rainbow Room of the Carter Hotel on Tuesday, October 28 at 7:00 pm. At 6:30 pm there will be a cocktail party in the foyer of the Rainbow Room for dinner guests. Tickets for the dinner will admit the holder to the cocktail party. Ladies are cordially invited to the cocktail party and dinner. Dress will be informal (business suits).

Dinner tickets will cost $6.50 each and will be on sale at the registration desk in the Carter Hotel during the meeting. Registrants are urged to buy their tickets early when they register to enable the Local Committee to plan the best party possible. The speaker of the evening is to be Dr. George B. Woolard, Department of Geology, University of Wisconsin.

National Metal Congress and Exposition: The Fall Meeting of The Metallurgical Society is part of the Annual Metal Congress. The American Society for Metals has its headquarters at the Hotel Cleveland and at the Statler Hilton. The annual ASM Seminar will be held on Saturday and Sunday, October 25 and 26, immediately preceding the opening of the National Metal Exposition at the Statler-Hilton Ballroom. The subject of the Seminar will be "Magnetic Properties of Metals and Alloys." At a Saturday evening meeting, Dr. G. W. Rathenau of the University of Amsterdam (Netherlands) will speak on "Time Effects in Magnetization." Also, on October 30 and November 1, there will be a Seminar on "Residual Stresses."

GENERAL INFORMATION

The ASM Campbell Memorial Lecturer will be Dr. Peter Payson, Assistant Director of Research, Crucible Steel Corp., who will speak Wednesday morning at 10:00 am in the Ballroom of the Statler-Hilton Hotel. His subject will be, "Tempered Alloy Martensites."

The National Metal Exposition is being held at the Public Auditorium and Exhibit Hall in Cleveland during the week of October 27-31. The Exposition will be open from noon until 10:30 pm on Monday, Tuesday, and Wednesday, and from 10:00 am to 6:00 pm on Thursday and Friday. Some 400 nationally known firms engaged in the production of metals, the treatment of metals, the fabrication of metals, or those firms rendering services to such companies, will exhibit their products, equipment, and services.

Volume V on "Nuclear Metallurgy"

The papers to be presented at the symposium arranged by the IMD Nuclear Metallurgy Committee on "Fabrication of Fuel Elements" have been printed in a book entitled, "Nuclear Metallurgy" (Vol. V).

Purchase your copy at the Registration Desk, or order by mail from AIME Headquarters, 29 West 39th Street, New York 18, N. Y.

(Copies of "Nuclear Metallurgy," Vols. I, II, III, and IV also available.)

Annual Dinner

Tuesday, October 28

6:30 pm, Rainbow Room Foyer
Cocktail Party for Dinner Guests

7:00 pm, Rainbow Room
Annual Fall Dinner

Toastmaster: W. J. Harris, Jr., Chairman
Institute of Metals Div.

Welcome: Edward Mapes, Chairman
Cleveland Section, AIME

Speaker: Dr. George B. Woolard,
Department of Geology,
University of Wisconsin,
Madison, Wisconsin

Special Luncheons

The IMD Semiconductors Committee, and the IMD Powder Metallurgy Committee will each hold a special luncheon following their technical sessions. The times and places are indicated below:

Semiconductors Luncheon, English Room, 12 noon, Monday, October 27.

Powder Metallurgy Luncheon, Oak Room, 12 noon, Thursday, October 30.

Price of luncheon ticket is $3.50. Tickets can be purchased at registration desk.

Calendar of Events

Sunday, October 26

11:00 am	IMD Council of Technical Committees (South Georgian Room)
2:00 pm	IMD Programs Committee Meeting (North Georgian Room)
3:00 to 9:00 pm	Registration (Mezzanine)
4:30 pm	IMD Publications Committee Meeting (South Georgian Room)

Monday, October 27

8:00 am	Breakfast for Monday Authors and Session Chairmen (Aviation Room)
8:00 am to 4:00 pm	Registration (Mezzanine)
9:00 am to 12m	Symposium on Point Imperfections (Lorenzo Carter)
9:00 am to 12m	General Metallurgy (Oak Room)
9:00 am to 12m	Oxidation and Mechanical Properties (Embassy Room)
9:00 am to 12m	Symposium on Government-Sponsored Research on Semiconductor Metallurgy (Lorenzo Carter)
12m	General Luncheon—Sponsored by IMD Semiconductors Committee (English Room)
12m	IMD Titanium Committee Luncheon Meeting (South Georgian Room)
12m	IMD Chemistry and Physics of Metals Committee Luncheon Meeting (North Georgian Room)
2:00 to 5:00 pm	Symposium on Effect of Ordering on Mechanical Properties (Ballroom)
2:00 to 5:00 pm	Annealing of Metals (Lorenzo Carter)
2:00 to 5:00 pm	Equilibrium and Microstructure (Oak Room)

2:00 to 5:00 pm	Deformation I (Embassy Room)
4:30 pm	IMD Membership Committee Meeting (North Georgian Room)

Tuesday, October 28

8:00 am	Breakfast for Tuesday Authors and Session Chairmen (Aviation Room)
8:00 am to 4:00 pm	Registration (Mezzanine)
9:00 am to 12m	Symposium on Effects of Small Dimensions (Lorenzo Carter)
9:00 am to 12m	Symposium on Physical Chemistry of Halide Systems (Embassy Room)
9:00 am to 12m	Symposium on Steelmaking in the Soviet Union (Oak Room)
9:00 am to 12m	Titanium Metal Symposium (I) (Ballroom)
12m	IMD Executive Committee Luncheon Meeting (Aviation Room)
2:00 to 5:00 pm	Titanium Metal Symposium (II) (Ballroom)
2:00 to 5:00 pm	Symposium on New Applications of the Phase Rule in Extractive Metallurgy (Embassy Room)
2:00 to 5:00 pm	Symposium on Steelmaking in the Soviet Union (Lorenzo Carter)
2:00 to 5:00 pm	Deformation II (Oak Room)
4:00 pm	IMD Nuclear Metallurgy Committee Meeting (South Georgian Room)
4:30 pm	IMD Awards Committee Meeting (South Georgian Room)

Wednesday, October 29

7:30 am	Metallurgical Society Program Committee Breakfast Meeting (South Georgian Room)
8:00 am	Breakfast for Wednesday and Thursday Authors and Session Chairmen (Aviation Room)
8:00 am to 4:00 pm	Registration (Mezzanine)
9:00 to 10:30 am	Symposium on Oxidation Protection and Fabrication (Ballroom)
9:00 to 10:30 am	High Purity Metals (Oak Room)
9:00 to 10:30 am	Precipitation and Segregation (Embassy Room)
9:00 am to 12m	Symposium on Ceramic Base Elements (Lorenzo Carter)
12:30 pm	Metallurgical Society Board of Directors Luncheon Meeting (Aviation Room)

GENERAL INFORMATION

2:00 to 5:00 pm	Symposium on Metal Base Fuels and Jacket Components (Lorenzo Carter)
2:00 to 5:00 pm	Symposium on Metallurgy of Columbium and Its Alloys (Ballroom)
2:00 to 5:00 pm	Symposium on Electrical and Magnetic Metals (Oak Room)
2:00 to 5:00 pm	Transformations (Embassy Room)
4:00 pm	IMD Surface Treatment Committee (South Georgian Room)

Thursday, October 30

7:30 am	IMD Powder Metallurgy Steering Committee Breakfast Meeting

GENERAL INFORMATION

	(South Georgian Room)
8:00 am to 3:00 pm	Registration (Mezzanine)
9:00 am to 12m	Symposium on Mechanical Properties and Effect of Interstitials (Ballroom)
9:00 am to 12m	Diffusion (Embassy Room)
9:00 am to 12m	Deformation and Fracture (English Room)
9:00 am to 12m	Symposium on Powder Metallurgy (Lorenzo Carter)
12m	General Luncheon—Sponsored by IMD Powder Metallurgy Committee (Oak Room)
2:00 to 5:00 pm	Symposium on Liquid Phase Sintering (Lorenzo Carter)

Monday, October 27

9:00 am to 12m, Lorenzo Carter

Symposium on
Point Imperfections

(Sponsored by the Chemistry and Physics of Metals Committee)

J. C. Fisher, Chairman

Irradiation Damage and Point Imperfections: J. W. Corbett, General Electric Co.

Internal Friction and Point Imperfections: C. A. Wert, University of Illinois.

Thermal Treatment and Point Imperfections: A. S. Nowick, I.B.M. Watson Laboratory, Columbia University.

9:00 am to 12m, Oak Room

General Metallurgy

(Session Based on Submission of Research Abstracts)

G. M. Ault and R. W. Fountain, Chairmen

Freezing of Liquid Metal in a Mold: G. Horvay and J. G. Henzel, General Electric Co.

Nomograms and charts are provided which permit rapid determination of the mold-ingot interface temperature and the speed of solidification when a semi-infinite ingot is cast into a semi-infinite mold. The physical properties of the mold, the frozen metal, and the liquid metal are not assumed to be equal, but they are assumed to be temperature independent. The results are correlated with charts prepared by Paschkis and Hlinka—using Columbia University's Analog Computer—for the freezing of finite ingot slabs when a constant surface temperature is impressed, and with experimental cooling curves obtained by Pellini in sand and iron molds for 7 in.-square steel ingots.

Gas Desorption of Nickel Powders: J. F. Watson, Convair Research Laboratories, and M. J. Sinnott, University of Michigan.

A study has been made of the gases desorbed from several types of commercial nickel powders when heated to elevated temperatures. The study included the determination of the amount, composition, and temperature-dependence of the desorption.

The results of these tests showed that a volume of gas of as much as 0.7 ml (STP) per gm of powder was evolved on heating to a temperature of 1800°F. All gas mixtures collected were composed of one or more species from a group consisting of H_2, H_2O, CO, CO_2, and SO_2.

The mechanism of gas evolution and the types of gas evolved from a given powder are dependent upon how the powder was produced and treated. Nickel powder produced by steam scattering in air desorbs CO_2, CO, H_2O, and SO_2 and the mechanism has been shown to be one of surface desorption. Powder produced by steam scattering, then annealing in cracked ammonia, evolves CO and minor amounts of H_2O, H_2, and CO. The CO and H_2O are formed from dissolved oxygen, carbon, and hydrogen while the H_2 and CO_2 are shown to be the products of reactions between H_2O and CO. Powder produced by precipitation from aqueous nickel ammonium complex solution evolve H_2, H_2O, and CO_2 and minor quantities of CO and SO_2. These gases are formed from dissolved elements in the metallic phase. Nickel powder produced by water atomization in a nitrogen atmosphere, followed by a hydrogen anneal at 1200°F, yielded only minor amounts of H_2 and CO_2 on desorption to temperatures of 1800°F.

Hydrogen in Cold Worked Iron-Carbon Alloys and the Mechanism of Hydrogen Embrittlement: M. L. Hill and E. W. Johnson, Westinghouse Electric Corp.

Cold working of iron-carbon alloys prior to treatments in hydrogen gas at pressures from 1 to 150 atm and temperatures from 200 to 400°C results in a large increase in the amount of absorbed hydrogen and a decrease in the hydrogen diffusivity. These effects become more pronounced with increasing carbon content and severity of deformation.

The supposition is made that only a fraction of the hydrogen in the cold-worked materials occupies interstitial lattice sites and that most of it is "trapped" in imperfections. The nature of the imperfections is considered and it is concluded that the hydrogen is not trapped in lattice defects such as vacancies and dislocations. Cracks which are observable by electron microscopy are formed during deformation of the two-phase pearlitic structure. The experimental results agree with the postulation that the hydrogen is trapped as chemisorbed atoms on these microcracks.

The problem of hydrogen embrittlement of steels is reconsidered in the light of this new evidence for the existence of cracks in cold-worked alloys. It is concluded that hydrogen embrittlement is a special aspect of the broader problem of brittle fracture of body-centered cubic metals. The major influence of hydrogen is that the energy or adsorption aids in the propagation of cracks under stress.

Aging of Hydrogen Charged Steel: H. C. Rogers, General Electric Co.

Is has been shown previously that when a mild steel or iron is charged with hydrogen, the normally observed yield point is eliminated or considerably reduced. In the present investigation the time-temperature relations associated with the yield point return were measured. The kinetics of the return of ductility to this same hydrogen embrittled steel was also measured so that the two processes could be compared.

Commercial rimmed steels were electrolytically charged with hydrogen at 100°C in a bath of dilute sulfuric acid poisoned with arsenic. These specimens were then aged in air furnaces and tested in tension.

The yield point (as well as the ductility) was shown to return upon aging. The activation energy for the yield point return was found to be about 25,000 cal per gm atom while that for the return of the ductility was 17,700 cal per gm atom. It was proposed that the disappearance of the yield point is a result of the growth of highly dispersed small regions of plastically deformed metal which arise during the charging process. The yield point should then return by the strain aging of these local regions. Therefore, the activation energies for the return of the yield point in the same steel after stretching through the yield point and after temper rolling to remove the yield point were measured. They were found in both cases to be identical and equal to that measured after hydrogen charging.

Additional experiments were performed that support the present hypothesis and do not support any of the previously proposed hypotheses regarding the mechanism by which hydrogen eliminates the yield point in mild steel.

The measurement of the activation energy for the ductility return is discussed. The measured value is compared with that for hydrogen diffusion at room temperature and above as measured or deduced by other investigators.

Fatigue in Single Crystals of Copper: M. L. Ebner and W. A. Backofen, Massachusetts Institute of Technology.

Single crystals of high-purity copper were deformed in alternating bending at constant deflection (plastic strain amplitude of approximately 0.2 pct). Hardening behavior was observed by continuous measurement of bending moment and was found to be similar to that under unidirectional straining, with an important difference being saturation at about 2000 cycles, independent of orientation. Fatigue cracks formed on active slip planes could only be observed after saturation and were always associated with patterns of intersection slip. The process of crack formation is considered to have begun with the onset of saturation. Depending upon whether the slip direction of the primary system cut through or lay in the free surface, primary-plane cracking either occurred exclusively or was effectively suppressed. In the latter case, cracking took place more slowly, predominantly on secondary planes, and life was approximately doubled. From the temperature dependence of hardening, work-softening effects, and metallography of slip bands, cross slip is suggested as essential for crack formation under the experimental conditions. A fracturing process is proposed in which surface steps from primary slip grow into cracks through the operation of dislocation sources provided by cross slip.

Hardening Characteristics of Polycrystalline Copper Under Fatigue Loading: M. L. Ebner and W. A. Backofen, Massachusetts Institute of Technology.

Polycrystalline OFHC copper was fatigued in alternating bending at constant deflection and the progress of hardening followed by measurement of bending moment throughout the period of cycling. Moment for cold-worked material was virtually constant with cycling; its dependence on deflection implied elastic deformation,

although a rapid X-ray line sharpening was observed to accompany cycling. In annealed material of two grain sizes, hardening occurred at a decreasing rate to saturation. A transition stress amplitude of approximately 20,000 psi, or a total strain of 0.1 pct, is suggested for distinguishing between low stress and high stress fatigue of the annealed material. In the former, the cycling forces at saturation are those for essentially elastic deformation and apparent structural changes are small. In the latter, the forces are those for partially plastic deformation and structural changes are more coarse and extensive.

Reduction of Nickel Oxide: R. E. Cech, General Electric Co.

The nucleating sites of nickel crystals formed by hydrogen reduction of single crystals of nickel oxide have been examined. All of the experimental evidence brought to bear on the problem is in agreement with the postulate that reduction of oxide in single crystals begins at points where dislocations intersect the surface of the oxide crystal.

Orientation relationships of reduced nickel crystals with respect to the parent oxide crystal have been determined using a pole-figure technique. A total of 14 reduction orientation relationships between nickel and nickel oxide were found. These were classified into four categories:

1. Orientation relationships which are identical to those formed upon oxidation of nickel single crystals.
2. One orientation relationship which allows each of the nickel atoms released from the oxide to reach an available site in the nickel crystal by a single jump across the reduction interface. Little or no diffusion of nickel parallel to the interface is required in the reduction process.
3. Two orientation relationships, each of which have simultaneously, a low index plane of nickel parallel to a low index plane of nickel oxide, and another low index plane parallel to a low index plane of crystals of nickel having the unique category 2 orientation. In each case the parallel low index planes are rotated such that there is a large fraction of coincident atom sites on a superposition plot representing the parallel planes.
4. A number of orientation relationships which appear to be due to recrystallization of reduced grains of nickel or growth of grains which were present in insignificant amounts after reduction.

Nucleation of Whiskers Formed by Reduction of Nickel Bromide: R. E. Cech, General Electric Co.

Nickel whiskers were grown on a substrate consisting of single crystals of nickel oxide. The oxide surface and internal structure near the sites where whiskers were formed was examined microscopically. Crystallographic orientations of whiskers were determined simultaneously with crystallographic orientations of the substrate oxide crystal.

The microscopic observations of nickel oxide crystal substrate provides evidence that whiskers nucleate at places where dislocations intersect the surface of the oxide crystal.

The crystallographic orientation relationship between nickel whiskers and nickel oxide substrate is near to one of the high-index orientation relationships produced by hydrogen reduction of nickel oxide.

9:00 am to 12m, Embassy Room

Oxidation and Mechanical Properties

(Session Based on Submission of Research Abstracts)

W. D. Robertson and M. Metzger, Chairmen

Oxide Particle Dispersions in Internally Oxidized Copper-Aluminum Alloys: D. L. Wood, General Electric Co.

Electron and light microscopy were used to study the particle size in internally oxidized copper-aluminum alloys. A discontinuous change from randomly distributed equiaxed particles to coarse strings of particles is observed under particular conditions.

Mechanical Properties of Internally Oxidized Copper-Aluminum Alloys: D. L. Wood, General Electric Co.

The hardness of the subscale of internally oxidized copper-aluminum alloys decreases with distance from the surface, as expected from the increase in oxide particle size and mean free path between particles. Although the yield strength is increased by internal oxidation, it is not influenced appreciably by variations in size and distribution of the oxide particles, but is dependent upon the matrix grain size. The increase in strength caused by internal oxidation is accompanied by a loss of ductility, particularly at higher temperatures. Elevated temperature ductility is considerably improved if major grain reorientation is accomplished by recrystallization prior to testing.

Recrystallization of Internally Oxidized Copper-Aluminum Alloys: D. L. Wood, General Electric Co.

When internally oxidized strips are cold rolled and annealed at a series of increasing temperatures, new recrystallized grains first appear near the central portion of the strip at relatively low-annealing temperatures. With increasing annealing temperature the recrystallization boundary moves outward toward the surface of the specimen. The observations appear to be in agreement with the increase in oxide particle size with increasing distance from the surface.

It is possible to produce oxide dispersions in copper-aluminum alloys that will prevent recrystallization of severely cold-worked material on annealing at a temperature of at least 0.94 of the melting point. In material that does not recrystallize, the amount of softening accompanying annealing depends on the solute content and on the degree of cold deformation.

Strengthening of Copper Alloys by Internal Oxidation: M. S. Ali and V. A. Phillips, General Electric Co.

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The tensile properties of Cu-0.20 pct Al, Cu-0.45 pct Mg, Cu-0.27 pct Cr and Cu-0.22 pct Be solid solution alloys were studied at −196°, 18°, 250°, and 500°C on wires internally oxidized at 900° and 1000°C. Internal oxidation produced marked increases in yield strength relative to pure copper, particularly at low temperature. The yield strength decreased with increase in temperature to a much greater extent than predicted by current theories of dispersion hardening. The hardening effect in internal oxidation persisted throughout the entire stress-strain curve, but since a marked loss of ductility occurred at all test temperatures, only modest increases in tensile strength were realized.

Effect of Oxygen on the Tensile Properties of Titanium: C. Feng, C. Elbaum, and W. C. Winegard, University of Toronto.

Tensile experiments, using a soft tensile machine, have been performed on titanium and titanium-oxygen alloys. The results indicate that the previously-reported increase of the yield strength with increase in oxygen content may be explained in terms of both an increase in the elastic limit and a very marked increase in the rate of work hardening. The results are interpreted in terms of simple dislocation-solute interaction theory.

Role of Oxide Plasticity in the Oxidation Mechanism of Pure Copper: J. A. Sartell, R. J. Stokes, S. H. Bendel, T. L. Johnston, and C. H. Li, Minneapolis-Honeywell Regulator Co.

The mechanism of the oxidation of high-purity copper has been studied at temperatures from 500 to 981°C employing gravimetric, high-temperature microscopic and inert marker techniques. An investigation of the adhesion of copper oxides was also made.

The oxidation of copper is found to be parabolic at all temperatures. It is concluded that the controlling mechanism is the outward diffusion of Cu^+ ions through the Cu_2O layer, but the mechanism of diffusion is modified by the state of compressive stress in the oxide layer at the oxidation temperature. At temperatures below the transition from elastic to plastic behavior of Cu_2O the growth stresses reach a value sufficiently high to cause CuO whiskers to be extruded. The extrusion of whiskers results in the injection of a large number of vacancies into the CuO. The Cu_2O layer grows by the advance of the Cu_2O-CuO interface into vacancy-rich CuO. Since there is an adequate supply of non-thermally created vacancies, the activation energy for oxidation is that required to move the Cu^+ ion through the appropriate saddle point to a neighboring vacancy, which has been determined to be 20,000 cal per mole. At temperatures at which the Cu_2O can deform plastically the stresses are never high enough to cause whiskers to form, thus vacancies must be supplied by thermal activation and as a result the activation energy increases to 40,000 cal per mole.

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Initial Oxidation Rate of Nickel and Effect of the Curie Temperature: H. Uhlig, J. Pickett, and J. MacNairn, Massachusetts Institute of Technology.

Nickel foil was oxidized for 24-hr periods within the temperature range 307° to 442°C producing NiO films up to 3400A thick maximum. A discontinuity in oxide growth is observed at the Curie temperature (353°C). Data obtained at 390, 394, and 405°C as a function of time show that a two-stage oxide growth rate occurs, a higher rate following an initially lower rate. Both stages are represented by a linear relation between oxide thickness and logarithm of time. Many initial oxidation rate data obtained by other investigators for Ni and a variety of metals, also follow the two-stage logarithmic equation.

Based on control of the initial oxidation rate by electron transfer from metal to oxide, the discontinuity of oxide thickness at the Curie temperature is explained by an observed work function of nickel slightly higher above the Curie temperature than below. The change of work function also explains a slightly higher activation energy for oxidation above the Curie temperature than below. Calculations show that the density of trapped electrons in a constant density space charge next to the metal surface is 1.3×10^{15} at 390°C. Density of available sites for trapped charge in a diffuse charge layer, which grows on top of the constant density layer, is the same order of magnitude (5.5×10^{15}). A higher density of sites for NiO than for Cu_2O, plus a higher work function for Ni than for Cu, are in line with a lower oxidation rate of Ni compared to Cu. It is calculated that contact of oxide with Ni or Cu lowers the work function at the metal-oxide interface by about 0.6 v. This value agrees, in the case of Cu_2O, with the energy required to excite an electron from the filled band to the conduction band.

9:00 am to 12m, Lorenzo Carter

Symposium on Government-Sponsored Research on Semiconductor Metallurgy

(Sponsored by the Semiconductors Committee)

D. C. Jillson and W. C. Hittinger, Chairmen

The Industrial Impact of Transistors: J. A. Morton, Bell Telephone Laboratories.

Review of Armed Services Activities: W. R. Cherry, Evans Signal Laboratory, U. S. Army; Richard Cornelissen, Air Force Cambridge Research Center; Paul Egli, Naval Research Laboratory.

2:00 to 5:00 pm, Ballroom

Symposium on Effect of Ordering on Mechanical Properties

(Sponsored by the Physical Metallurgy Committee)

Paul Shewmon and John Hirth, Chairmen

Deformation Characteristics of Superlattices: P. A. Flinn, Westinghouse Electric Corp.

The lowering of symmetry upon the formation of a superlattice has the consequence that a dislocation of the parent disordered structure is not a true dislocation of the ordered structure. As pointed out by Cottrell, such dislocations may be expected to occur in pairs, connected by a strip of antiphase boundary. In addition antiphase boundary will normally be present in some systems as a consequence of the ordering process. At low temperatures the nature of the deformation is determined by the interaction of the dislocation pairs with antiphase boundary. The effect of this interaction on the yield strength and work hardening of ordered alloys will be discussed.

At elevated temperatures, where diffusion can occur during deformation, the mechanism of deformation may become more complicated. The configuration in which the two dislocations lie in the same slip plane is not necessarily the one of lowest energy. When it is not, the resulting rearrangement to a configuration of two dislocations on different slip planes connected by antiphase boundary impedes slip. As a consequence, an increase in high temperature yield strength and creep resistance is observed. Measurements on an ordered nickel-base alloy will be reported in which these effects are observed.

Deformation and Annealing of the Alloy Cu_3Au: J. B. Cohen, B. Roessler, and M. B. Bever, Massachusetts Institute of Technology.

Deformation: Polycrystalline specimens of ordered and disordered Cu_3Au were cold worked by wire drawing and rolling. The resulting changes in the mechanical properties were measured by tensile and microhardness tests. Changes in energy content and electrical resistivity were determined; structural effects of the deformation were investigated by X-ray diffraction.

In tensile tests ordered specimens strain hardened more rapidly than disordered specimens. Hardness tests confirmed this behavior. The energy content of the ordered material, initially smaller than that of the disordered, increased rapidly and at the largest strains investigated ($\bar{\epsilon} = 2.26$) approached the value for disordered material; the resistivity showed a similar pattern. After cold working the superstructure peaks in X-ray patterns had broadened in a different manner than the fundamental peaks. These effects may be interpreted in terms of domain size reduction.

Annealing: Specimens of ordered and disordered Cu_3Au were rolled to a strain of $\bar{\epsilon} = 1.03$. These specimens, as well as disordered specimens that had not been cold worked, were annealed about 100°C below the critical temperature. This treatment induced ordering, as shown by X-ray intensity and resistivity measurements. The microhardness initially increased and gradually decreased during further annealing. The initial increase in hardness, attributed to ordering, was not accompanied by a loss of the effects of strain hardening in the cold worked specimens; half-breadth measure-

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ments of the X-ray peaks indicated that only recovery had taken place and metallographic observation confirmed the presence of a cold worked microstructure.

Effect of Order on the Plastic Behavior of Iron-Aluminum Alloy: F. X. Kayser, Ford Motor Co.

The solid solubility of aluminum in α-iron extends beyond 32 at. pct. Within this solution at least two superlattices, an Fe_3Al and an FeAl type, are known to exist and there are reports that a third, of the $Fe_{13}Al_5$ type, also occurs. In this investigation, the plastic behavior of polycrystalline, vacuum melted, alloys containing up to 32 at. pct Al was studied. Samples at 43 alloys were tested in tension at various temperatures, and at a fixed strain rate, after rigorously annealing from 760°C. Prior to testing, the states of the specimens were determined by electrical resistivity measurements. The boundaries observed for the Fe_3Al region were in good agreement with published results. Resistivity and density anomalies were noted in the vicinity of the $Fe_{13}Al_5$ field proposed by Taylor and Jones but these were not explainable on the basis of a well defined superlattice.

At any fixed tests temperature from 200 to 400°C, the flow stress (defined at any fixed plastic strain from 0.005 to 0.20 pct) increased slowly through the region devoid of long range order. At the boundary of the Fe_3Al superlattice region it increased to a maximum. At the aluminum concentration within this region approached 25 at. pct, the flow stress decreased to a minimum accompanied by the appearance of a yield point. This behavior persisted to about 28 at. pct where the flow stress began to increase slowly and the yield point disappeared. The results are discussed in terms of first and second order transformation models.

Effect of Ordering on the Mechanical Properties of Beta Brass: N. Brown, University of Pennsylvania, and M. Herman, Franklin Institute.

The results and interpretations of the investigations of the order-disorder phenomena in beta brass will be presented. Particular attention will be given to the effects of ordering on the mechanical properties and to a proposed description of the imperfection model accounting for some of the effects.

The property measurements to be discussed are: (1) the stress-strain characteristics in compression, the density, and the electrical resistivity as a function of quenching temperature, aging temperature, and aging time; and (2) the creep properties and the yield point as a function of degree of order. Polycrystalline and some single crystals were used for these studies.

The results of the creep and yield point measurements show that appreciable strengthening occurs as the material orders. The increase is above that which could be expected from the temperature change accompanying the increasing amount of order. Aging experiments on the quenched samples indicate that the kinetics of the process appear controlled by the diffusion of vacancies.

The model suggested to account for the results is based on the pairing of dislocations of like sign in the ordered portion of the crystals.

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Anneal-Hardening in Aluminum Bronze: R. W. Cahn, S. Chinowsky, and R. G. Davies, University of Birmingham, England.

Ordinary α-brass, and also Cu-Al solid solutions, fail to soften if, after cold-working, they are annealed at temperatures too low to cause recrystallization. Instead they become harder. The kinetics of this hardening have been studied at temperatures in the range 100 to 300°C, both by hardness measurements and by tensile tests. Experiments on the intensity of X-rays diffusely scattered by Cu-Al alloys in various conditions of heat-treatment show that quenched alloys acquire short-range order if annealed in the above range of temperature; this is confirmed by observed changes in lattice parameter. It is, however, not yet certain that the observed anneal-hardening is wholly or even partly attributable to the re-establishment of short-range order destroyed by the preceding cold work, since further X-ray studies have shown that the cold-worked alloys contain large stacking-faults, and there is also some indirect X-ray evidence for the segregation of solute to these stacking-faults; this effect may be responsible for some hardening. Experiments on the behavior of alloys annealed after quenching from high temperatures will also be reported.

Ordering and Creep Properties of Iron-Aluminum Alloys: A. Lawley, University of Pennsylvania, and R. W. Cahn, University of Birmingham, England.

The ordering characteristics of Fe-rich Fe-Al alloys (19 to 50 at. pct Al) have been studied by means of a high-temperature X-ray Geiger counter diffractometer. Experiments were carried out (a) isothermally, (b) at various heating and cooling rates. Intensity-temperature plots for superlattice diffraction lines show that there is no discontinuous increase of long-range order at the critical temperature T_c (~540°C). For alloys containing 24.8 and 25.5 at. pct Al the cooling rate through T_c has a profound effect on subsequent ordering; on cooling from $T_c + 50$°C to $T_c - 50$°C at ~50°C per min, a permanent reduction in the stable degree of order is observed at all lower temperatures. It is necessary to reheat to temperatures considerably above T_c in order to remove the effects of this treatment. The reduction of equilibrium order following rapid cooling through T_c is attributed to the build-up of a uniaxial short-range order, linked to the magnetization vector in each magnetic domain, of the type recently proposed by Néel to explain the *permalloy problem*.

The creep resistance of alloys with 24.8 and 27.8 at. pct Al was studied in the range 490 to 680°C. In each case, steady state creep, without any transient creep, is observed above T_c. Near T_c, the stress appears to disorder the structure, causing a *gradual increase* in creep rate. A recovery treatment re-establishes the original creep-rate; this is attributed to renewed ordering. The initial creep rate, when plotted against temperature, shows a distinct discontinuity at T_c.

2:00 to 5:00 pm, Lorenzo Carter

Annealing of Metals

(Session Based on Submission of Research Abstracts)

R. F. Hehemann and R. P. Carreker, Jr., Chairmen

Effect of Atmosphere on Secondary Recrystallization in High-Purity Silicon-Iron: J. L. Walter and C. G. Dunn, General Electric Co.

Under certain conditions of processing and annealing high purity silicon-iron will form a cube texture by secondary recrystallization. The occurrence of this phenomenon was first reported by Assmus, et al.[1] Walter and Dunn have shown that the secondary cube texture may be replaced by a (110)[001] texture by *tertiary recrystallization*. It was further shown that the driving force for growth of the (110) grains was derived from the existence of a difference in surface free energy between the (100) grains and the growing (110) grains.

The present paper describes the secondary recrystallization behavior of high purity 3 pct silicon-iron when subjected to different atmospheres during the growth anneal.

The effect of annealing in an inert atmosphere such as argon is such as to produce only the cube texture when the material is annealed at temperatures of 1200 to 1300°C for times up to 16 hr. Similar material when annealed in dry hydrogen or vacuum first forms the (100)[001] texture (2 hr at 1200°C) by secondary recrystallization. Conversion to the (110)[001] texture by tertiary recrystallization occurs in an additional hour at 1200°C. Use of higher vacuum (0.008_{μ}) decreases the time and temperature required for complete secondary recrystallization.

From these and other observations it is believed that the selection of the particular grains for secondary growth depends upon the rate at which the particular atmosphere is able to remove interstitial impurities such as oxygen, carbon, etc. The impurity element itself determines which grains grow probably by virtue of a lowering of the surface energy of the growing grains relative to the other grains of the material.

[1] Assmus, et al.: Zeit. fur Metallkunde, 1957, vol. 48, p. 341.
[2] J. L. Walter and C. G. Dunn: "Tertiary Recrystallization in Silicon-Iron." To be published.

Initial Growth Behavior of a Secondary Recrystallization Cube-Oriented Nucleus: C. G. Dunn and J. L. Walter, General Electric Co.

The initial growth behavior of a cube-oriented nucleus in a 3 pct silicon-iron alloy of high purity has been studied during a sequence of anneals. This material secondarily recrystallizes to a cube or (100)[001] texture and will develop a cube-on-edge or (110)[001] texture by tertiary recrystallization.

The cube-oriented nucleus was selected after an annealing treatment designed to initiate secondary recrystallization. The nucleus had twelve neighbors and a diameter of about five times the sheet thickness. The matrix grains had diameters about two times the sheet thickness. The orientations of the nucleus and the surrounding grains were determined by the transmission Laue method. The positions of the grain boundaries for the first anneal and for all subsequent anneals were revealed by thermal grooves. The grooves left from a prior boundary position had flat bottoms. Present boundary positions were revealed by sharp V shaped grooves.

Among the matrix grains surrounding the (100) nucleus was one with a (110) orientation. Other grains had orientations near this. The (100) nucleus was seen to grow at the expense of the (110) grain.

The driving force for secondary recrystallization was expected to involve both a grain boundary term and a surface energy term. Surface energy driving forces are known to be involved in the

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growth of the {110} grains during tertiary recrystallization. Here the surface energy of the {110} grain has been found to be lower than the surface energy of the {100} grain into which it grows.[1]

The relative importance of these two kinds of driving forces in secondary recrystallization therefore determines whether a particular {100} oriented grain will grow into a grain with a {110} plane in the plane of the sample or will be consumed by it.

The observations made on boundary migration provide information on the growth of the cube oriented nucleus and on the nature of the driving forces involved in that growth.

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[1] J. L. Walter and C. G. Dunn: Tertiary Recrystallization in Silicon-Iron. To be published.

Secondary Recrystallization in Silicon-Iron: J. E. May and D. Turnbull, General Electric Co.

Effects of impurities on the {110}[001] secondary recrystallization texture were studied by making specific impurity additions to high-purity silicon-iron. The primary recrystallization texture was found to be very weak, but a {110}[001] component was detected. It was found that the presence of impurities is necessary in order for the strong {110}[001] texture and secondary recrystallization to develop. The impurities formed a dispersed second phase. A function of the inclusions is to inhibit normal grain growth and thus maintain the driving energy for secondary recrystallization. An analysis was made of the combined effects of inclusions and texture on the driving energy for secondary recrystallization. The results are consistent with the analysis. In order to account for the strong {110}[001] texture, it seems necessary to suppose that ($\Sigma + U_d$) is lower for {110}[001] grains in material with impurities than other components of the primary recrystallization texture (Σ is the specific surface energy and U_d is the residual strain energy).

Tertiary Recrystallization in Silicon-Iron: J. L. Walter and C. G. Dunn, General Electric Co.

High-purity silicon iron under certain conditions of processing and annealing will undergo secondary recrystallization to a cube texture. On prolonged heating the secondary recrystallization texture may be replaced by a cube-on-edge or {110}[001] texture. We have called this phenomenon tertiary recrystallization. The circumstances of the growth of the tertiary grains were such that the usual driving force for grain growth, the grain boundary energy, was not responsible for the growth of these grains. The paper describes the structures obtained in vacuum-melted silicon-iron before and after tertiary recrystallization. The alloy used consisted of 3 pct Si in iron with a total impurity content of approximately 0.005 wt pct.

The material was rolled to 0.012 in. and 0.006 in. thick and the kinetics of tertiary recrystallization ascertained when the material was annealed in a vacuum. From the shape of the growing {110}[001] grains and from the direction of motion of the boundaries at the surface it was decided that surface energy and not grain boundary energy was the driving force for growth of these grains during tertiary recrystallization. Measurements of boundary curvatures both at the surface and in the radial cross section were used to compute the difference in surface energies between the growing {110} grain and the disappearing {100} grains. A value of approximately 70 ergs per sq cm was obtained as the difference in surface energy at temperatures of 1100° to 1200°C. Equations were also derived to ascertain the critical radius of curvature for growth of the {110} grains.

On the Determination of Preferred Orientations: C. G. Dunn, General Electric Co.

Orientation data for individual grains after growth in two differently treated cold-rolled materials, but having the same primary recrystallization texture and fine-grained structure, are used to construct both pole density figures and axis density figures. Axis density figures are found to give more complete information on a weak texture composed of several components or preferred orientations than a single {100} pole figure gives. Neither type of figure, however, completely records original data. For example, grain growth in secondary recrystallization in the fine-grained matrix produces a strong {110}[001] texture, whereas grain growth after a 1.5 pct cold-rolling strain produces no orientation within 7° of an exact {110}[001] orientation. The pole density and axis density figures, of course, indicate that one of the preferred orientations is shifted some from the {110}[001] position, but they register the presence of isolated poles and isolated axis directions which confuse the true situation.

Magnetic torque data are also correlated with the textures.

The significance of the missing orientations within 7° of {110}[001] for strained and annealed material, when such orientations are not only present but are favored for the unstrained and annealed material, is discussed in connection with oriented nucleation and oriented growth theories. Also the effect of the strain is discussed in connection with known strain-induced grain boundary migration phenomena.

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Temperature Dependence of Preferred Orientation in Rolled Tungsten: J. W. Pugh, General Electric Co.

The preferred orientation of cold-rolled tungsten was evaluated as a function of annealing temperature by means of pole figures. Additional information was obtained from back reflection powder patterns and photomicrographs.

The as-rolled texture was found to be centered about the orientation {100}<011>. Annealing did not produce a change of texture below 1800°C. Above 1800°C a new texture based on the double orientation {100}<011> ±12° develops. Alternatively, this can be described as corresponding approximately to the orientations {001}<320> and {001}<230>. Microstructure is observed to coarsen as the annealing temperature is increased to 1800°C. For treatments above 1800°C, larger and more regularly-shaped grains were detected.

An analysis of these observations in terms of polygonization, substructure growth, and recrystallization was made.

X-Ray Diffraction Study of the Perfection of Aluminum and Copper Crystals Grown in the Solid State: M. N. Parthasarathi and P. A. Beck, University of Illinois.

If proper precautions are taken in handling specimens and in supporting them during annealing, the perfection of aluminum crystals grown by coarsening (secondary recrystallization) is of a high order. The absence of any low angle boundaries in crystals grown by either inhibition-dependent or texture-dependent coarsening suggests that the mechanism of nucleation proposed under the name of *geometric coalescence* is not likely to play an important role. The perfection of strain-anneal crystals grown in 2S aluminum is also very high. However, many crystal imperfections clearly observable by the X-ray diffraction method used were noted in strain-annealed crystals grown in high-purity aluminum, particularly when the penultimate grain size was large. Only a few of the strain-annealed high purity aluminum crystals had detectable low angle boundaries, and only one of the 97 crystals examined was found to have a *nuclear spot*. The findings do not furnish support for the hypothesis that the mechanism of nucleation of strain-annealed crystals is based on strain-induced boundary migration.

Annealing of Point Defects in Cold-Worked Tungsten and the Influence of Impurities on the Kinetics: L. A. Neimark, Argonne National Laboratory, and R. A. Swalin, University of Minnesota.

The kinetics of the "low-temperature" recovery of electrical resistivity of both pure and specially doped cold-worked tungsten wire has been studied. The doping additions were those normally added to achieve creep-resistant properties at high temperatures. Significant recovery, presumably due to annihilation of point defects is found to occur above 250°C. The recovery process, in the temperature interval investigated, appears to occur in two main stages, the second stage starting at about 350°C in the undoped wire and 375°C in the doped material. The first stage is characterized by an activation energy of 1.5eV and 1.2 eV for the undoped and doped tungsten respectively. The second stage has an activation energy of 1.7eV and 2.3eV for the undoped and doped wire respectively. Recovery in the second stage is ascribed to the migration and annihilation of vacancies at dislocations and the difference of 0.6eV observed for the two materials is thought to represent the binding energy of vacancy-impurity atom pairs. It is calculated that defects make fewer jumps before annihilation in the doped than in the undoped material indicating a closer proximity of the defect-impurity atom pairs to dislocations in the doped material. The role of the special impurity additions has been the subject of considerable speculation. This study suggests that the minute amounts of impurities play a direct role in inhibiting recrystallization and not the indirect role of creating porosity which then inhibits recrystallization as has been suggested.

Temperature Dependence of Grain Boundary Migration in High-Purity Lead Containing Small Additions of Tin: K. T. Aust and J. W. Rutter, General Electric Co.

The striation (lineage) structure of melt-grown single crystals of zone-refined lead containing various additions of tin was utilized to provide a driving force for grain boundary migration. Each grain boundary under study separated the striated single crystal from another grain which was introduced by localized plastic deformation and recrystallization of a small region of the sample. Growth of the recrystallized grain at the expense of the striated one made possible measurement of the rate of motion of individual, known boundaries as a function of composition and temperature.

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Measured values of the temperature dependence of the rate of boundary migration in samples of different compositions show that the apparent activation energy for migration in the temperature range from 200 to 320°C is markedly dependent upon the tin concentration and upon the type of grain boundary under study. In the case of high-angle boundaries separating crystals in random relative orientation, the apparent activation energy increased from about 15 to 40 Kcal per gm atom as the tin concentration was increased from 0.0001 to 0.0015 wt pct. In the case of high-angle grain boundaries separating crystals which bear any one of several special crystallographic relationships to one another (e.g. crystals related by a rotation of approximately 40° about a common [111] axis), the measured apparent activation energy was 6 Kcal per gm atom. This value was independent of tin concentration in the composition range studied, which was from about 0.0005 to 0.002 wt pct Sn. These special boundaries are similar to those which Kronberg and Wilson predicted should have high mobility.

The experimental observations are compared with the predictions of a number of theories of grain boundary migration.

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2:00 to 5:00 pm, Oak Room

Equilibrium and Microstructure

(Session Based on Submission of Research Abstracts)

Pol Duwez and E. A. Peretti, Chairmen

Zirconium and Hafnium Phases Isostructural With Ti_2Ni: M. V. Nevitt and L. H. Schwartz, Argonne National Laboratory.

A group of phases isostructural with Ti_2Ni has been found which contain zirconium in combination with rhodium, iridium, or platinum, and hafnium in combination with rhodium, palladium, iridium, or platinum. There is an indication that all of the zirconium phases and the hafnium-palladium phase occur only when sufficient oxygen is present. However, the range of solubility of oxygen in each of these phases is not yet known. Lattice parameters of these new Ti_2Ni-type phases are as follows:

System	Nominal Composition, At. Pct	a_0, A
Zr-Rh	20 Rh	12.476 ±0.001
Zr-Ir	25 Ir	12.47
Zr-Pt	25 Pt	12.574 ±0.006
Hf-Rh	30 Rh	12.3255±0.0002
Hf-Pd	25 Pd	12.3605±0.0003
Hf-Ir	30 Ir	12.352 ±0.001
Hf-Pt	30 Pt	12.461 ±0.001

Lattice parameters generally increase with increasing B element radius.

Ternary System Zirconium-Silicon-Boron: Erwin Parthe and J. T. Norton, Massachusetts Institute of Technology.

The ternary system Zr-Si-B has been investigated, chiefly by X-ray methods, and a section of the ternary phase diagram at 1400°C has been established. In the Zr-B and Zr-Si binaries, the previously reported phases have been confirmed. In the Si-B binary no intermediate phases were observed but a crystalline modification of boron was prepared with a rhombohedral structure. The parameters are: $a = 10.14$A, $\alpha = 65°$.

In the ternary system, the only ternary phase observed was that previously reported by Nowotny and co-workers having the formula $Zr_3Si_2B_2$ with a $D8_8$ structure and containing about 5 at. pct boron. The system is compared with the other Me-Si-B systems recently reported.

Use of Controlled Solidification in Equilibrium Diagram Studies: W. A. Tiller, Westinghouse Electric Corp.

At present, there is considerable interest in the preparation of homogeneous single crystals of multicomponent alloys by the zone-levelling technique. To utilize fully this method it is necessary to know the distribution coefficients of the constituents between the liquid and the solid phases for the alloys of interest. This tie-line information cannot be determined using the conventional cooling and heating curve techniques for determining the liquidus and solidus surfaces in more than a two component system; thus, new methods must be devised to provide this information in multicomponent systems.

It will be shown theoretically how the use of controlled solidification in phase diagram studies enables one to determine both the liquidus and solidus surfaces *plus tie-lines* for a polycomponent alloy with no limitations on the number of constituents. The method also allows one to determine the types of phase boundaries present in the system, i.e., peritectics, eutectics, etc.

The method is a very general and straightforward one; however, its accuracy depends upon the fulfilment of certain experimental conditions. It is necessary to stir the melt during solidification to such an extent that the convectionless layer at the solid-liquid interface is almost completely eliminated. This serves a two-fold purpose (a) the experimentally determined distribution coefficients approached to within 1 or 2 pct of the phase diagram distribution coefficient and, (b) dendrite formation is eliminated.

Solid-Liquid Phase Equilibrium in the Bi_2Te_3-Bi_2Se_3 Pseudo-Binary System: J. P. McHugh and W. A. Tiller, Westinghouse Electric Corp.

The Bi_2Te_3-Bi_2Se_3 pseudo-binary system has been investigated using the conventional heating and cooling curve techniques and by a new controlled solidification technique.

The solidus and liquidus lines were determined by thermal analysis carried out on carefully prepared compacts of Bi_2Te_3-Bi_2Se_3 powders. Homogenization was achieved with much shorter annealing times than those generally required for conventional chill cast specimens. The techniques used gave reproducibility of a few tenths of a degree on the heating and cooling curve arrests.

The controlled solidification technique involved slowly lowering an ampule of molten alloy through a spiral shaped induction coil in the Bridgeman manner. The sample freezes slowly upward and the liquid is kept well mixed by eddy-current stirring. Sections were cut from various positions of the crystal bars for both metallographic and chemical analyses. The metallographic analysis verified the adequacy of the growth conditions, i.e., dendrites were not present in the samples. The chemical analysis yielded the composition as a function of position in the sample. From the chemical data the distribution coefficients for Te, Se, and Bi across the phase diagram were determined.

The results of the thermal analysis and the controlled solidification are compared and show that the distribution coefficients found by the two methods agree to within 2.5 pct. The usefulness of the controlled solidification technique is therefore substantiated.

CsCl-Type Equiatomic Phases in Binary Alloys of Transition Elements: A. E. Dwight, Argonne National Laboratory.

Equiatomic alloys of 57 binary systems in which both partners are transition elements, were investigated for the occurrence of the CsCl-type phase. Eighteen examples of this phase were found, 10 of which were previously unreported. The lattice parameter a_0 was accurately measured for the 18 CsCl-type phases, and the lattice contraction was calculated. Lattice contraction is defined as $D_{AB}-d_{AB}$, where D_{AB} is the average of the two Goldschmidt diameters for C.N. 8 and d_{AB} is $\sqrt{3}/2 \times a_0$. It was found that lattice contractions decrease in the order; HfOs, ZrOs, HfRu, ZrRu, HfCo, and ZrCo; i.e., lattice contraction is greatest when both *A* and *B* elements are in the third long period.

It was found that relative size of the *A* and *B* elements is not a controlling factor in formation of CsCl-type phases. CsCl-type phases were found with D_A/D_B ratios varying from 1.014 to 1.416. For the 39 systems in which no ClCs-type phase was found, the D_A/D_B ratios also varied in a similar range from 0.985 to 1.439.

The position of the *A* and *B* elements in the periodic table appears to be a major controlling factor in the occurrence of ClCs-type phases. Of the 18 such phases studied in this investigation, none involve a member of the Cr group or the Mn group. A literature search of all CsCl-type phases known up to 1955 also confirms that the Cr group does not participate. It was also noted that an *A* element lying relatively far to the left of the Cr Group has for a partner a *B* element lying relatively far to the right of the Cr Group, and conversely, if one partner lies close to the Cr Group, the other partner also lies close. This observation indicates that formation of the CsCl-type phase is largely dependent on an electron-sharing arrangement between an electropositive and an electronegative element.

Effect of Chromium on the Stability of Cementite: George Sandoz and B. F. Brown, U. S. Naval Research Laboratory.

Diffusion couple experiments involving irons of different chromium content were carried out which demonstrate that the relative positions of the cementite and graphite solubility lines of the iron-carbon diagram (Acm and Agraphite lines) may be changed by the presence of alloying elements. The presence of sufficient amounts of chromium was shown to cause the solubility lines to reverse positions, thereby making orthorhombic cementite the thermodynamically stable phase with respect to graphite and austenite saturated with graphite.

The experiments suggest an explanation for the conflicting data in the literature relative to the positions of the Acm and Agraphite lines for *pure* iron-carbon alloys. Some published experimental procedures for determining these two solvus lines have involved treatments of alloys in vacuo whereas other procedures have required the presence of hydrogen-containing atmospheres. Hydrogen, like chromium, is known to suppress graphitization, and may well cause a similar shifting of the solubility lines.

The experiments further cast doubt on certain attempts in the literature to employ *activation-energy* determinations as a means of identifying the mechanisms by which alloying elements influence graphitization rates in irons. To be valid, such *activation-energy* methods require that the solubility difference between cementite and graphite in austenite remain constant with changing temperature. This cannot be the case with chromium-bearing irons, for partition data show that the chromium content of the cementite varies with the total amount of cementite in the iron, which is in turn related to temperature. As the temperature is raised the chromium content of the cementite must increase and the solubility difference between cementite and graphite must decrease, as shown by the diffusion couple experiments.

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2:00 to 5:00 pm, Embassy Room

Deformation I

(Session Based on Submission of Research Abstracts)

A. D. Schwope and W. R. Clough, Chairmen

Anomalous Effect of Hydrogen on the Mechanical Properties of Ti-8 Mn and Ti-4 Al-4 Mn Alloys: A. H. Fleitman, Crane Co.

The mechanical properties of two commercial alloys, Ti-8 Mn and Ti-4 Al-4 Mn were investigated in the as received, helium annealed, vacuum annealed, and 150, 225 and 300 ppm hydrogen conditions. The Ti-8 Mn alloy in the form of 1/16 in. sheet and the Ti-4 Al-4 Mn alloy in the form of ½ in. round bar were each ordered from three vendors to represent the range of interstitial content found in present production.

Slow room temperature notched and unnotched tensile and tensile stress rupture tests up to 1000 hr were performed on both alloys. Slow room temperature notched and unnotched torsion, bend and bend stress rupture tests up to 1000 hr were made on Ti-4 Al-4 Mn alloy. None of the unnotched specimens in any of these tests failed in a brittle manner. The notched tensile stress rupture tests showed that the stress required for fracture at 1000 hr slightly decreased with increasing hydrogen content with one exception. In contrast, the notched bend stress rupture tests showed an increase in stress required for fracture.

Longitudinal and transverse tear tests at 80, 32 and −40°F were made on the Ti-8 Mn alloy sheet in the vacuum annealed and 300 ppm hydrogen condition. No apparent relationship was found between tear test failures and hydrogen content.

Room temperature unnotched slow tensile tests on prestrained and aged specimens showed good ductility in both alloys. Specimens in the vacuum annealed and 300 ppm hydrogen condition were prestrained 5 pct in tension at room temperature and aged at 500°F for 48 hr prior to test.

Comparison of results in this investigation with earlier work on hydrogenized specimens of these titanium alloys indicates that brittle fractures would have been expected in both alloys when tested in stress rupture at the 300 ppm hydrogen level and that the stress required for rupture in 1000 hr would show a sharp drop at 300 ppm hydrogen.

Effect of Complexing on Mechanical Properties of Ti-6 Al-3 Mo Alloy: F. A. Crossley, Armour Research Foundation, and W. F. Carew, Joliet Metallurgical Laboratories, Inc.

Tensile, creep-rupture and stability tests were employed to evaluate the effect of α-strengthening and β-complexing additions on the base composition Ti-6Al-3Mo. The ultimate objective was to produce an alloy of greater strength than the Ti-7Al-3Mo alloy. Strengthening of α was accomplished by additions of 2 and 4 pct Ge, 4 pct Sn, 4 pct Zr and 2 pct Sn-2 pct Zr. Beta was complexed while keeping the total of β-stabilizing additions constant at 3 pct. The β additions of alloys with binary β stabilization were: 2 pct Mo-1 pct Cr, 2 pct Mo-1 pct Mn and 2 pct Mo-1 pct V; while those of alloys with ternary β stabilization were: 1 pct Mo-1 pct Mn-1 pct Cr and 1 pct Mo-1 pct Mn-1 pct V.

From this investigation the following conclusions are drawn:

(1) The addition of the α strengtheners 2 pct Ge, 4 pct Ge, 4 pct Sn, 4 pct Zr, or 2 pct Sn-2 pct Zr to the base composition Ti-6Al-3Mo produced increased tensile strength without detriment to ductility except for the 4 pct Ge addition.

(2) In general, substituting 1 pct Mn or 1 pct Cr for 1 pct Mo of the base alloy produces increased tensile strength without detriment to ductility. The substitution of 1 pct V for 1 pct Mo apparently has a slight weakening effect.

(3) The addition of α strengtheners to the base alloy improves 1000°F rupture strength. In order of decreasing effectiveness they are: 4 pct Ge, 2 pct Sn-2 pct Zr, 4 pct Sn and 4 pct Zr. The position of the 2 pct Ge addition in this sequence is uncertain because of microstructural differences.

(4) The 4 pct Zr addition and possibly the 2 pct Ge addition do not improve creep resistance at 1000°F. The α-strengthening additions 4 pct Ge, 4 pct Sn and 2 pct Sn-2 pct Zr increase creep resistance over that of the base alloy at 1000°F.

(5) Excluding from the comparison the Ti-6Al-2Mo-1Mn alloy because of its different microstructure, the β-complexed alloys are inferior in creep resistance at 800 and 1000°F and inferior in rupture strength at 1000°F to the base alloy. Furthermore, at 1000°F the alloys containing three β-stabilizing metals are inferior to those containing two. Evidently, β complexing, although beneficial to short-time elevated temperature properties, is detrimental to long-time properties.

(6) In agreement with previous findings for Ti-Al-Mo alloys, the base composition Ti-6Al-3Mo is stable following exposure to stress at 800°F for 300 hr. Of the α-strengthened group of alloys, Ti-6Al-3Mo-4Ge and Ti-6Al-3Mo-4Zr are also stable; while the Ti-6Al-3Mo-2Ge, Ti-6Al-3Mo-4Sn and the Ti-6Al-3Mo-2Sn-2Zr alloys are unstable. Of the β-complexed alloys only Ti-6Al-2Mo-1Mn and Ti-6Al-2Mo-1V are stable. The data imply that the addition of 2 pct or more of tin to an alloy containing 6 pct Al produces structures that are unstable under conditions of long-time exposure to stress at 800°F.

(7) Since the superior strength performance of the Ti-6Al-3Mo-4Ge alloy is offset by its poor ductility, none of the alloys investigated show more promise than the Ti-7Al-2Mo alloy.

A Decision Technique for Evaluating the Effect of Melting and Casting Environments on Stress-Rupture Properties: J. T. Brown, Westinghouse Electric Corp.

Stress-rupture tests were performed on a new nickel-base high-temperature casting alloy intended for use as a turbine blade material at 1800°F.

Seven heats of the alloy, each heat yielding nine stress-rupture specimens, were prepared by varying their processing procedure as follows: vacuum melted and cast, vacuum melted and cast under argon, vacuum melted and cast in air, vacuum melted stock remelted and cast under argon, vacuum melted stock remelted and cast in air, melted and cast under argon, and melted and cast in air.

Stress-rupture tests at two conditions, 1800°F-25,000 psi and 1700°F-30,000 psi were made in triplicate on each heat. The decision technique for evaluating the processing conditions involved ranking the heats with respect to each other for average rupture time, average elongation, and spread in rupture time between tests. A value was determined for each property, and the relative ranking of each heat was established. This technique revealed that either vacuum or argon melting and casting resulted in good properties. When melted or cast in air, the alloy displayed poorer and less predictable properties.

Room temperature tensile tests were made in duplicate and the results are included along with macro-photographs of the fractures of the stress-rupture specimens and photomicrographs at 500X magnification of the structure. These results are qualitatively correlated with the properties.

Absolute values of the stress-rupture properties also show the new alloy to be significantly stronger and able to be used at higher temperatures than any commercial alloy.

Short-Time Creep of Some Graphites at 3000-5300°F: H. E. Martens, L. D. Jaffe, and D. D. Button, California Institute of Technology.

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The constant-load tensile creep properties of three commercial grades of synthetic graphite were determined at 3000 to 5300°F, using times up to 8 hr. The specimens had a gage section ¼-in. diam by 1 in. long and were heated in helium by an external graphite heater. Creep rates of 10^{-7} to 10^{-2} sec^{-1} were observed at stresses of 1600 to 4000 lb per sq in. The creep rate increased continually with increasing temperature and did not show a minimum corresponding to the peak found in the tensile strength at approximately 4500°F. The creep rate was lower parallel to the grain than perpendicular to it. Activation energies of 170-270 Kcal/mole were obtained using the rate process theory expression $\dot{\varepsilon} = Ae^{\frac{-\Delta H}{RT}}$. Elongations greater than 5 pct caused decreases in density. Elongations up to 30 pct and density decreases up to 16 pct occurred during tensile creep testing.

Ductility of Polycrystalline Ceramics: C. E. May, H. H. Grimes, and R. A. Lad, National Advisory Committee for Aeronautics.

It has recently been shown that single crystals of sodium chloride and magnesium oxide can be made to exhibit considerable ductility at room temperature. This ductility is very sensitive to the condition of the crystal surface.

Polycrystalline specimens of sodium chloride were formed by compacting crushed salt prepared from melt-grown single crystals. The ductility of the polycrystalline specimens was determined in flexure as a function of various surface treatments. Some of the surface treatments used were made on the bulk, compacted specimen, but most of them were performed on the powders before compacting.

To date, only two of the treatments tried imparted any ductility to sodium chloride specimens. These were: (1) treatment with an ether solution of stearic acid and (2) vapor deposition of a thin film of silver; both treatments were performed on the powder before compacting. In all cases increased ductility was accompanied by a lowered fracture stress, and ductility occurred even at very low loads. In contrast, untreated specimens exhibited Hookean behavior right up to the fracture point. Other treatments of the powder, such as vapor deposition of copper or chromium, and chemical precipitation of a thin film of calcium hydroxide, did not enhance the ductility. Various heat treatments and X-irradiation had no effect on the Hookean behavior of the salt.

Effect of Surface Condition on the Initiation of Plastic Flow in Magnesium Oxide: R. J. Stokes, T. L. Johnston, and C. H. Li, Minneapolis-Honeywell Regulator Co.

A method has been developed to study the influence of environment on the operation of surface dislocation sources responsible for the initiation of plastic flow in magnesium oxide single crystals. Dislocation half-loops are artificially introduced into the crystal by first sprinkling with carborundum. Use is then made of the stress gradients along the tension surface of a crystal subjected to three point loading to identify the different stages of loop expansion. The dislocation distribution after loading is revealed by etch pits and correlated with the macroscopic stress strain behavior.

Artificially induced half-loops start to expand at a stress level only one third of the yield stress while at two thirds of the yield stress multiplication is first observed. Preliminary results indicate that these values are independent of the *age* of cleaved surfaces exposed to both dry and wet air. The aged surface layer thus imposes no additional restriction on the motion of dislocations as proposed by Aerts and Dekeyser[1] and Gorum et al.[2] to explain observations on sodium chloride.

For unsprinkled crystals slip is not detected until the stress exceeds two thirds of the yield stress. Thus the stress required to *activate* "normal" dislocation sources is approximately *twice* that to *move* dislocations through the lattice.

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The results provide further evidence that resistance to dislocation motion takes the form of a viscous drag rather than a static or Peierls-Nabarro type of force.

[1] E. Aerts and W. Dekeyser: *Acta. Met.*, vol. 4, p. 557, 1956.
[2] A. E. Gorum, E. R. Parker, and J. A. Pask: *J. Am. Ceram. Soc.*, vol. 41, p. 161, 1958.

Three Dimensional Ductility and Crack Propagation of Preferentially Oriented Beryllium Sheet: F. M. Yans and A. R. Kaufmann, Nuclear Metals, Inc.

Elongation of approximately 20 to 30 pct have previously been achieved in beryllium sheet which has been fabricated by extrusion and cross-rolling. The texture of this sheet is one in which the (0001) planes (the main fraction planes) are oriented parallel to the plane of the sheet and the (1120) planes (the secondary fraction planes) are oriented transverse to the plane of the sheet at 30 and 90° to the rolling direction. This sheet yielded almost no third dimensional ductility and exhibited severe anisotropic crack propagation and fracture.

A new process has been developed whereby elongation of approximately 20 to 25 pct can still be achieved, but the material has a good measure of third dimensional ductility and fractures in a completely isotropic fashion eliminating, to a large degree, crack propagation.

This new sheet is made by applying purely compressive forces to a cylindrical beryllium billet along its longitudinal axis. The billet consists of cold-compacted beryllium powder inside a steel can. In effect, the process is the same as rolling from an infinite number of directions.

The texture resulting from this operation is the key to the advantageous change in the mechanical properties. The (0001) planes are mainly oriented parallel to the plane of the sheet and the (11$\bar{2}$0) planes are transverse to the plane of the sheet and randomly oriented with respect to any direction within the plane of the sheet.

The third dimensional ductility of upset, extruded and cross-rolled, and hot-pressed sheet has been investigated by performing bend tests on specimens with varying width to thickness ratios. The upset sheet exhibited better strengths and third dimensional ductility.

The fabrication was performed at 1950°F and the best lubricant was found to be glass. Fifty sheets have been made by this technique with a 100 pct yield, i.e., no cracking whatsoever. In all other techniques of producing beryllium sheet to date, a 50 pct yield is considered admirable.

Creep of a Dispersion-Hardened Aluminum Alloy: G. S. Ansell and J. Weertman, United States Naval Research Laboratory.

The creep behavior of an aluminum-aluminum oxide alloy, fabricated from fine flake aluminum powders, was investigated. This alloy was tested in both the as-extruded and recrystallized forms.

The as-extruded alloy shows a quasi-steady-state creep region in which the steady-state creep rate depends exponentially on the applied stress. The activation energy of creep was approximately 150,000 cal per mole. The recrystallized alloy shows extremely erratic and unusual creep behavior. No steady-state creep was observed in this material.

Creep equations for dispersion hardened, coarse grained alloys are derived from work previously done.[1] This derivation assumes that there are active dislocation sources in the alloy. The experimental data are in complete disagreement with the derived theory. It is concluded that the alloy tested has at most only a few active dislocation sources within the grains. The difference in creep behavior of the two forms of the alloy is attributed to the large difference in grain size present in each material.

[1] J. Weertman: *J. Appl. Phys.*, vol. 28, p. 362, 1957.

Tuesday, October 28

9:00 am to 12m, Lorenzo Carter

Symposium on
Effects of Small Dimensions
(Sponsored by the Chemistry and Physics of Metals Committee)

B. D. Cullity and S. S. Brenner, Chairmen

Properties of Whiskers: N. Cabrera, University of Virginia.

Mechanical Properties of Thin Films: J. W. Beams, University of Virginia.

Magnetic Properties of Whiskers, Thin Films, and Small Particles: C. P. Bean, General Electric Co.

TUESDAY, OCTOBER 28

9:00 am to 12m, Embassy Room

Symposium on
Physical Chemistry of Halide Systems

(Sponsored by the EMD Physical Chemistry of Extractive Metallurgy Committee)

J. H. Downing and T. B. King, Chairmen

Factors Affecting the Rate of Deposition of Metals in Thermal Dissociation Processes: G. H. Kesler, Battelle Memorial Institute.

Use of Heat and Mass Transfer Model Studies in the Evaluation of the Rates of Deposition of Metals in Complex Systems: G. H. Kesler and J. H. Oxley, Battelle Memorial Institute, and C. E. Dryden, Ohio State University.

Iodide Columbium: R. F. Rolsten, E. I. du Pont de Nemours and Co., Inc.

Iodide columbium was prepared by the thermal decomposition of columbium iodide(s) on an indirectly heated quartz surface. The metal was deposited on and easily removed from the quartz surface without contamination. Various commercial grades of columbium were used and, in all cases, the columbium deposited was considerably purer than the commercial material. Typical analyses of three pounds of iodide columbium are:

0.033—0.059 pct oxygen
0.001—0.005 pct nitrogen and
0.001—0.005 pct carbon

Some of the results of melting columbium at reduced pressure, results of rolling arc melt buttons at −196°C, change of hardness and grain growth at various annealing temperatures are discussed in a cursory manner.

9:00 am to 12m, Oak Room

Symposium on
Steelmaking in the Soviet Union

(Sponsored by Iron and Steel Division)

John Chipman and David Swan, Chairmen

Raw Materials: J. B. Austin, United States Steel Corp.

Blast Furnaces and Coking: J. H. Strassburger, National Steel Corp.

Open Hearths: M. F. Yarotsky, United States Steel Corp.

Electric Furnaces: K. C. McCutcheon, Consultant, Ashland, Kentucky.

9:00 am to 12m, Ballroom

Titanium Metal Symposium (I)

(Sponsored by the Titanium Committee)

W. E. Lusby, Jr., and A. L. Rustay, Chairmen

Price, Quality, and New Process Prospects for Titanium Sponge, Ingot, and Billet:
Panel:
Graham Brown, Mallory-Sharon Metals Corp.
D. H. Baker, Jr., U. S. Bureau of Mines.
G. A. Moudry, Harvey Aluminum Co.

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W. E. Lusby, Jr., E. I. du Pont de Nemours and Co., Inc.

Summary Address:
H. H. Kellogg, Columbia University.

Price Trends and Market Analysis of Titanium Products: R. L. Vroome, Electro Metallurgical Co., Division of Union Carbide Corp.

Current and New Uses of Titanium in Missiles, Aircraft, and Aircraft Power Plants:
Panel:
W. H. Sharp, Pratt and Whitney Aircraft, Div. of United Aircraft Corp.
A. Hurlich, Convair Astronautics.
L. J. Hull, Ryan Aeronautical Co.

2:00 to 5:00 pm, Ballroom

Titanium Metal Symposium (II)

(Sponsored by the Titanium Committee)

N. E. Promisel and L. S. Busch, Chairmen

Status and Use of Titanium Abroad: To Be Announced.

Review of Department of Defense Sheet Rolling Program: N. E. Promisel, Navy Bureau of Aeronautics (to summarize Phases I and II); and George Sachs, University of Syracuse (to summarize Phase III).
Panel: C. W. Alesch, Convair.
T. H. Gray, Boeing Airplane Co.
W. W. Wood, Chance Vought Aircraft, Inc.

New Alloys:
Moderator: R. I. Jaffee, Battelle Memorial Institute.
Panel: Harold Margolin, New York University.
S. A. Herres, Titanium Metals Corp. of America.
W. L. Finlay, Crucible Steel Co. of America.
T. E. Perry, Republic Steel Corp.
L. S. Busch, Mallory-Sharon Metals Corp.

2:00 to 5:00 pm, Embassy Room

Symposium on
New Applications of the Phase Rule in Extractive Metallurgy

(Sponsored by the EMD Physical Chemistry of Extractive Metallurgy Committee)

R. Schuhmann, Jr., and L. S. Darken, Chairmen

Graphical Representation of Heterogeneous Ternary Equilibria: J. H. Downing, Electro Metallurgical Co., Div. of Union Carbide Corp.

Heterogeneous Equilibria in Multicomponent Systems: L. S. Darken, U. S. Steel Corp.

Recent Studies of Geological Materials at High Pressures and Temperatures: J. F. Schairer, Carnegie Institute of Washington.

Representation and Interpretation of Phase Equilibria in Oxide Systems Involving Changes in

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Oxidation States: A. Muan, Pennsylvania State University.

Derivation of the Approximate Ternary Phase Diagram Silicon-Oxygen-Carbon: W. A. Krivsky, Electro Metallurgical Co., Div. of Union Carbide Corp.

Quaternary Systems: R. Schuhmann, Jr., Purdue University.

2:00 to 5:00 pm, Lorenzo Carter

Symposium on
Steelmaking in the Soviet Union
(Sponsored by Iron and Steel Division)

TUESDAY, OCTOBER 28

John Chipman and David Swan, Chairmen

Rolling Mills: F. S. Eckhardt, Bethlehem Steel Corp.

Alloy Steels: Gunther Mohling, Allegheny Ludlum Steel Corp.

Vacuum Techniques in Metallurgy in the Soviet Union: A. M. Aksoy, Crucible Steel Company of America.

Observations on the Direction of Steelmaking Research and Development in the Soviet Union: J. F. Elliott, Massachusetts Institute of Technology.

2:00 to 5:00 pm, Oak Room

Deformation II

(Session Based on Submission of Research Abstracts)

J. E. Dorn and C. M. Wayman, Chairmen

Slip in Aluminum-Silver Single Crystals: A. Kelly, A. Lassila, and S. Sato, Northwestern University.

Stress-strain curves have been obtained of single crystals of Al-20 wt pct Ag aged varying amounts in the cold-hardening state. The temperature dependence of the flow stress of these crystals has also been measured and compared with that of pure aluminum. A striking difference is found; the flow stress of the alloy crystals depending no more on temperature than do the elastic constants over the temperature range 77 to 373°K.

The slip lines observed on the surface of the alloy crystals are similar to those found in body-centered cubic metals, and it is concluded that the dislocations in this alloy behave as if they are undissociated. This behavior may be accounted for by the large stresses needed to produce slip in the alloy if the stacking fault energy is about the same in pure aluminum.

Experimental Observations of Some Dislocation Sources: J. J. Gilman, General Electric Co.

By means of a new technique, the sites where dislocation loops are nucleated in LiF crystals have been investigated. Very short stress pulses (~1μsec) are applied to the crystals. These pulses allow sufficient time for dislocation loops to nucleate, but not enough time for them to grow appreciably. This makes it easy to see where a group of loops has originated. Treatments of various kinds can then be given to the crystals, and their effects on dislocation nucleation can be observed.

Several kinds of crystal inhomogeneities have been found that act as dislocation nucleation catalysts. These are: (a) large cleavage steps (higher than ~1000A); (b) pre-existing glide bands; (c) inclusions; (d) precipitate needles; and (e) small point-defect clusters. With the exception of the last one, the mechanisms by which the catalysts operate is straightforward. The clusters are produced by radiation damage and present evidence indicates that they need be only a few atoms in size before they become effective nucleation catalysts. This is inexplicable by present theory.

Photographic Evidence of Frank-Read Dislocation Sources in Zinc: V. Damiano and M. Herman, Franklin Institute.

Single crystals of pure zinc and zinc alloyed with small amounts of cadmium were cleaved, etched, and examined under the light and electron microscope. The loops and spirals observed appear as the configuration predicted by Frank and Read as sources for dislocations.

The particular pictures to be shown reveal the circular loops and spiral generating sources, loops generating from subboundaries, and loops formed around twins.

Dislocation Behavior During Creep of Silver—I. The Initial Creep Period: M. S. Abrahams and E. S. Machlin, Columbia University.

Silver single crystals of the same orientation were tested under conditions of tensile creep. Dislocation populations in these specimens were measured. The strain-time curves exhibited an initial linear period. The structure sensitivity of this initial creep rate was accounted for by a measured difference in initial dislocation population. The ratio of the initial creep rate to the initial dislocation density was found to be structure insensitive, i.e., this ratio was invariant for a given set of test conditions over all the crystals tested.

Existing creep theories were evaluated. Only one theory was found in agreement with all the experimental results. In this model, the rate controlling process during the linear creep period is the formation of vacancies at jogs in moving screw dislocations. The measured activation energy was 17,100 cal per mole.

The initial linear creep period ceases suddenly and the rate becomes less than the measurable sensitivity. It is believed, as a consequence of observation of the dislocation behavior, that the sudden onset of hardening corresponds to a critical value of the ratio of the Lomer dislocation density to the primary slip band dislocation density.

Flow Stress of Iron and Its Dependence on Impurities: G. C. Schoeck, Westinghouse Electric Corp., and A. Seeger, Max Plank Institut fur Metallforschung, Stuttgart, Germany.

It has been recognized for a long time that the yield phenomenon in iron and other BCC metals is closely connected with the presence of impurities in interstitial position.[1] However, a complete understanding of the process is still missing and the existing theories have serious shortcomings especially with respect to experimental observations above room temperature.

A theory is proposed where the flow stress of iron above room temperature is mainly determined by the Snoek-effect occurring around moving dislocation lines. The atomic mechanism is as follows: In the stress field of a dislocation a local ordering of interstitial carbon (or nitrogen) atoms takes place. This is because interstials in different types of interstial sites have different interaction energies with the dislocation line. By this ordering a locking of the dislocation takes place because the energy of the dislocation is lowered due to rearrangement of carbon atoms. Since this locking is accomplished by interstials merely jumping to neighboring lattice sites, it can take place in times orders of magnitude smaller than it would take to form *Cottrell-atmospheres*.

If the dislocation moves, the centre of the "ordered Snoek-atmosphere" lags behind the dislocation and hence a frictional force results. The absolute value of this frictional force is calculated and it is shown that the force is independent of temperature and linearly proportional to the concentration of carbon atoms in solid solution. The calculated values are compared with experimental results from the literature and excellent agreement is found with respect to magnitude[2, 3], temperature dependence[3, 4], and concentration dependence[4] of the flow stress.

[1] A. H. Cottrell and B. A. Bilby: *Proc. Phys. Soc.*, vol. A 62, p. 49, 1949.
[2] N. P. Allen, B. E. Hopkins, and J. E. McKenan: *Proc. Roy. Soc.*, vol. A 234, p. 221, 1956.
[3] F. L. Vogel and R. M. Brick: *AIME Trans.*, vol. 197, p. 700, 1953.
[4] F. Heslop and N. F. Petch: *Phil. Mag.*, vol. 1, p. 866, 1956.

Effect of Changes in Slip Direction on the Creep of Magnesium Crystals: Hans Conrad, Westinghouse Electric Corp.

The strain-hardening associated with the creep of Mg single crystals at room temperature was investigated by shear tests in which the direction of stressing was reversed a number of times after creep in a <100> direction. The strain-hardening was strongly anisotropic; the largest amount occurring in the direction of flow and the least 180° to this.

The time law for creep changed from a parabolic type to logarithmic for the first and subsequent reversals of stress. For a given stress the creep decreased significantly for the first and second reversals and then only slightly for subsequent reversals. The logarithmic creep constant α changed in a similar manner.

A linear relationship was observed between the creep strain for a given reversal and the stress. The slope for the third reversal yielded a strain-hardening coefficient 12 to 16 times greater than that observed for unidirectional flow. Although no recovery was observed upon resting at room temperature, the hardening resulting from stress reversals could be completely removed by heating to 450°C.

Activation Energies for Creep of Single Aluminum Crystals Favorably Oriented for Cubic Slip: Y. A. Rocher, L. A. Shepard, and J. E. Dorn, University of California.

Creep activation energies for single aluminum crystals favorably oriented for shear by {010}⟨101⟩ glide were determined over the temperature range from 78° to 900°K. The study was undertaken to determine whether or not the oft reported high-temperature cubic slip actually occurs in aluminum. Observations of slip bands on the specimen surface were made in conjunction with the investigation.

From 78° to 775°K, the activation energies agreed closely with those previously found for creep by (111)[101] slip; by the Peierls process to 140°K with an activation energy of 3400 cal per mole, and by (111) and (111) cross-slip above 260°K with an activation energy of about 30,000 cal per mole. Thus, the coarse wavy slip bands nominally parallel to the (010) plane observed above 260°K were attributed to fine cross-slip on the (111) and (111) planes rather than (010) glide.

From 800° to 900°K, unusually high activation energies ranging from 28,000 to 54,000 cal per mole were obtained. The maximum activation energy was attributed to recrystallization.

Factors Affecting Ductility and Strength of NaCl Single Crystals Tested in Flexure: C. A. Stearns, A. E. Pack, and R. A. Lad, National Advisory Committee for Aeronautics.

The strength and ductility of ionic single crystals have been reported to be extremely sensitive to the mode of preparation of the specimen. This work was undertaken in an attempt to provide a quantitative comparison of the effect of carefully controlled treatments which caused changes in the surface and bulk structure.

Sodium chloride single crystals were tested in flexure and, in addition to load-deflection data, load-strain data were obtained by bonding strain gages to the compression or tension surfaces of the specimen. Neither the load-deflection nor the load-strain curves exhibited the linear regions which would be expected from the elastic modulus of the material. Water polishing only the compression surface reduced the yield stress while water polishing the tension surface increased ductility. Water treatment of the entire crystal resulted in both an increase in ductility and a decrease in yield stress. Annealing reduced the yield stress and quenching in CCl_4 increased the yield stress. X-irradiation which primarily affected a thin layer near the surface caused an increase in hardness and a decrease in ductility.

Taylor has suggested that FCC single crystals should obey a law of the form $P = NE^{1/2}$. The load-compressive strain curves were found to fit the equation $P = NE^m$ where m varied from 0.45 for untreated crystals to 0.32 for water treated ones and 0.35 for annealed crystals. The load-tensile strain curves were markedly different in shape.

The results will be discussed in terms of the change in dislocation structure and vacancy concentration and distribution produced by various treatments.

Wednesday, October 29

9:00 to 10:30 am, Ballroom

Symposium on
Oxidation Protection and Fabrication

(Sponsored by the Refractory Metals Committee in Conjunction With the High Temperature Alloys Committee)

P. C. Rossin and W. L. Havekotte, Chairmen

Nucleation and Growth of Chromium on Molybdenum in Liquid Metal Solutions: J. Wulff and S. T. Wlodek, Massachusetts Institute of Technology.

Arc Melting and Fabrication of Tungsten: S. J. Noesen, J. R. Hughes, C. L. Kolbe, and R. C. Leech, General Electric Co.

Orientation of Large Grains in Annealed Tungsten Wire: A. J. Opinsky and J. L. Orehotsky, Sylvania Electric Products, Inc.

Arc Melting, Fabrication, and Annealing of Tantalum to Produce Foil: S. J. Noesen, M. A. Cocca, and R. C. Leech, General Electric Co.

9:00 to 10:30 am, Oak Room

High Purity Metals

(Session Based on Submission of Research Abstracts)

W. A. Johnson and M. W. Mallett, Chairmen

Growth of Molybdenum, Tungsten, and Columbium Crystals by Floating Zone Melting in Vacuum: E. Buehler, Bell Telephone Laboratories, Inc.

A vacuum floating zone apparatus using r.f. heating has been employed to grow single crystals of tungsten, molybdenum, and columbium. A marked improvement in purity is achieved by a single pass run through tungsten and molybdenum. Studies of the electrical and physical properties of these crystals are now in progress. The results will be published at a later date.

Determination of the Limiting Segregation of Gallium in Zone-Refined Germanium: L. W. Davies, Commonwealth of Australia.

The paper describes an experimental determination of the ultimate distribution of a solute in an ingot subject to Pfann's zone-refining process. Germanium is used as solvent, and the concentration of the solute gallium is determined from measurements of

electrical resistivity. The results are compared with the theoretical distribution derived by the author, and are found to be in good agreement when a value $k = 0.18$ is used for the distribution coefficient of gallium in germanium; this value is consistent with the accepted equilibrium value $k = 0.10$ and the experimental conditions.

Zone Melting of Magnesium: A. S. Yue, Dow Chemical Co.

A description is given of an apparatus used to zone-refine magnesium. A flexible skin was successively introduced on the surface of the molten metal to suppress severe vaporization. The distribution of impurities along the length of the bar to be purified were determined by spectrographic analysis. The effects of the zone speed and the number of passes of the molten zone on the purification have been determined. The values of the effective distribution coefficients of the alloying and impurity elements in magnesium determined by this technique are in good agreement with those obtained from the phase diagrams.

9:00 to 10:30 am, Embassy Room

Precipitation and Segregation

(Session Based on Submission of Research Abstracts)

J. W. Spretnak and J. B. Newkirk, Chairmen

Metallographic Study of Precipitation of Silicon From a Supersaturated Al(Si) Solid Solution: H. S. Rosenbaum, General Electric Co.

The precipitation of silicon (diamond cubic) from a supersaturated Al (1 pct Si) solid solution FCC was studied qualitatively by X-ray diffraction and by both light and electron microscopy. It was found that the precipitated silicon occurs as both plate-like and equi-axed particles.

In specimens that were water quenched to room temperature from the homogenizing temperature (580°C) and then aged isothermally at 180 to 370°C, the precipitated silicon was found to exhibit strong preferred orientations with respect to the matrix. However, no exact, or Widmanstätten, orientation relation was found. The following orientation preference were observed.

1. $\{111\}_{Si} \parallel \{100\}_a; \langle 110\rangle_{Si} \parallel \langle 100\rangle_a$
2. $\{111\}_{Si} \parallel \{111\}_a; \langle 110\rangle_{Si} \parallel \langle 114\rangle_a$
3. $\{111\}_{Si} \parallel \{111\}_a; \langle 111\rangle_{Si} \parallel \langle 123\rangle_a$
4. $\{111\}_{Si} \parallel \{110\}_a; \langle 112\rangle_{Si} \parallel \langle 100\rangle_a$

where a refers to the Al-rich matrix. The data do not exclude the possibility for the orientation

$\{111\}_{Si} \parallel \{111\}_a; \ [110]_{Si} \parallel [110]_a$

where the lattices are nearly identically oriented. The orientation preferences, as manifested by the reflection of characteristic radiation from the precipitated particles, were found to diminish (i.e., become more random) as over-aging occurred.

The grain boundaries exhibited a depleted region bounded by the grain boundary itself and by a region of coarse precipitation. When the alloy was plastically deformed at room temperature prior to aging, the precipitate particles were found to be larger and more widely spaced than in unstrained regions.

In samples that had been air cooled instead of water quenched from the homogenizing temperature, there resulted on subsequent aging far fewer precipitate particles ($\sim 10^6$ per cm^3 as compared with $\sim 10^{14}$ per cm^3 in quenched samples). In air-cooled samples the preferred orientations were not found; the samples did not exhibit the depleted regions near grain boundaries; and plastic deformation had no observable effect on dispersion of the particles.

Acoustical Study of G. P. Zone Formation After Reversion in Al-20 Wt. Pct. Ag: Herbert Herman and M. E. Fine, Northwestern University.

Using an acoustical method, the kinetics of reaging after reversion in a single crystal Al-20 wt pct Ag alloy were investigated. Reaging after reversion was studied at four temperatures between 50 and 150, and the results compared with the kinetics for aging after directly quenching from the solution temperature of 525°C. The method employed, which essentially enabled the measurement of the change in the dynamic Young's modulus as precipitation proceeded, showed that the kinetics on reaging after reversion are similar to that observed on aging after the direct quench, though decidedly slower.

No incubation time has been detected in any of the above experiments, indicating that nuclei are present after reversion. The determination of an activation energy of approximately 8 Kcal per mole and a time law for growth have given information concerning the growth mechanism. The exponent of time in the rate equation for growth of the zones on directly aging after quenching from 525°C is $\frac{1}{2}$ and 1 on reaging after reversion. The rate of formation of the zones is anomalously large indicating that, as in aging after the direct quench, there is a defect mechanism available for reaging after reversion which permits the rapid movement of silver atoms to the zones. A supersaturation of vacancies or edge dislocations acting as pipelines or a combination of these two defects may be of significance for the growth of the zones.

Critical Particle Size for Precipitation Hardening: J. D. Livingston, General Electric Co.

The tensile properties of alloys of 0.7, 1.3, 2.0, and 3.2 pct Co in copper have been measured as a function of aging time at several temperatures. Magnetic measurements have been used to determine such parameters as the volume fraction of precipitate and the average size of the precipitate particles. As has been reported earlier,[1] the precipitation is essentially complete well before the peak in yield stress. It is now found that the various alloys, aged at various temperatures, reach their peak yield stress at approximately the same average particle, radius. This radius is about 70A.

From magnetic measurements reported elsewhere the precipitate is known to be equiaxed particles of FCC cobalt coherent with the copper-rich matrix. The experimental results describing the precipitation hardening are interpreted in terms of the internal stresses resulting from the coherence between matrix and precipitate. It is suggested that the critical particle size for peak yield stress is the size at which the particles begin to lose their complete coherence, i.e., where dislocations first appear in the particle—matrix interface.

[1] J. D. Livingston and J. J. Becker: *A Study of Precipitation Hardening Employing Magnetic Measurements*, *AIME Transactions*, vol. 212, p. 316, 1958.

Correlation Between Sub-Boundaries and Impurities in Super-Purity Aluminum: D. Altenpohl, Aluminum Foils, Inc.

The results of electron microscopic pictures (replica and transmission as well) and of recrystallization tests are presented. Investigated are mainly purities from 99.99 pct Al up, and for comparison also 99.8 and 99.5 pct Al. All samples are polycrystalline. Sub-boundaries are detected after cold deformation as well after recovery or recrystallization. The dimensions of the sub-structures are strongly dependent on very small impurities in super-purity aluminum (purity above 99.993). There is a correlation between the behavior of the metal during recovery and recrystallization and the results of the electron microscopic pictures. The results indicate that atoms which are smaller than the aluminum atoms tend to segregate at grain boundaries and sub-boundaries. Segregated iron (and copper?) atoms are probably obstacles for grain growth during recrystallization.

Finally, there are observations that the corrosion behavior of super-purity aluminum in water or water vapor above 230°F, is strongly dependent on the smallest impurities in aluminum above 99.993 pct Al. It will be discussed whether the reason for this is the same as for the changing of recrystallization temperature and sub-grain size of the same material.

Also, the question will be discussed as to whether the substructures visible with electron microscope are sub-grain boundaries with measurable difference in orientation or veining of foreign atoms which are in single-phase segregation. The results of transmission pictures of recrystallized super-purity aluminum indicate equilibrium segregation of iron (and copper?) atoms in two dimensional veins, with a diameter of several hundred A. Other experiments, based on metallographic etching, indicate accumulation of hydrogen atoms in veins, which are inside recrystallized grains running parallel ⟨100⟩.

9:00 am to 12m, Lorenzo Carter

Symposium on Ceramic Base Elements

(Sponsored by the Nuclear Metallurgy Committee)

F. G. Foote and A. R. Matheson, Chairmen

Fabrication of Ceramic Fuel Elements by Swaging: D. R. Stenquist and R. J. Anicetti, General Electric Co.

WEDNESDAY, OCTOBER 29

Ceramic fuel materials can be simultaneously compacted and clad by swaging to form relatively inexpensive feul elements. The feasibility of manufacturing ceramic fuel elements by the swaging process will depend principally upon the densities obtainable, the reproducibility of the product, and the irradiation behavior of the fuel assembly. Both a stationary swage and the more common rotary swage have been used to fabricate UO_2 fuel elements for ex-reactor and in-reactor evaluation. It has been determined that important variables in the swaging process include the characteristics of the UO_2 powder, the composition, wall thickness, and outside diameter of the cladding, and the temperature at which the swaging operation is conducted. The design of the swaging dies also is important. At room temperature, certain UO_2 powders have been compacted to densities of 89 to 92 pct of the theoretical. Untreated, "PWR grade" UO_2 has been compacted to 93 pct of the theoretical density by swaging at elevated temperatures. The density of any given type of UO_2 powder after swaging is reproducible to within ±1 pct of the theoretical density. Details of the equipment, techniques, and important variables in swaging ceramic fuel elements are reviewed and preliminary data from in-reactor tests are described.

Pressure Bonding of Zircaloy-Clad Flat-Plate Uranium Dioxide Fuel Elements: S. J. Paprocki, E. S. Hodge, and D. C. Carmichael, Battelle Memorial Institute.

A technique utilizing gas pressure at elevated temperatures is being investigated for the preparation of Zircaloy-clad flat-plate compartmented uranium dioxide fuel elements. The work is sponsored by the Bettis Atomic Power Laboratory because of their interest in the potential usefulness of this type of fuel element in the Pressurized Water Reactor. In this process, the components are fabricated to final size and assembled into a container which is evacuated and sealed. The sealed assembly is then subjected to high gas pressures at temperatures sufficient to readily deform the Zircaloy by plastic flow.

The process appears promising for this application, as the operation is accomplished without deformation of the brittle uranium oxide and bonding is achieved on all Zircaloy mating surfaces.

Surface preparation of the Zircaloy components is important to the attainment of good bonding, as there is essentially no deformation occurring during the bonding cycle. The effects of various surface treatments on the subsequent bond quality have been investigated. The best results were obtained with annealed Zircaloy surface conditioned by a belt-grinding technique. Heat treatments after pressure bonding have also been investigated. Bonds with incomplete grain growth across the interface are improved by heat treatments involving phase transformations.

The use of barrier materials to prevent or minimize reaction between the uranium dioxide and Zircaloy has also been investigated. Both metallic iron and chromium are effective barrier materials.

Fabrication of Aluminum Plate-Type Elements Containing Uranium Dioxide as the Fuel: S. I. Megeff and J. L. Zambrow, Sylvania-Corning Nuclear Corp.

A method is described for the fabrication of plate-type fuel elements in which the fuel is a dispersal of UO_2 in an aluminum matrix. Advantages of the method as compared to use of a cast alloy discussed are: (1) uranium as an oxide is purer than the metallic form; (2) reduction to metal is avoided; (3) less scrap is formed in the processing of fuel plates; (4) fewer steps are involved in the making of plates; (5) UO_2 can easily be recovered for recycling, if necessary; (6) burnable poisons can be added accurately and uniformly; (7) concentration gradients in fuel content can be used.

The following properties of the fuel plate are also discussed: (1) uniformity of fuel distribution; (2) dimensional tolerances on core and clad; (3) end effects; and (4) integrity of bonds.

Stainless Steel-Uranium Dioxide Fuel Components for Army Package Power Reactor: J. E. Cunningham and R. J. Beaver, Oak Ridge National Laboratory.

This paper covers the design, manufacture, and operation characteristics of the fuel components developed for the Army Package Power Reactor. The technological factors, such as compatibility, corrosion resistance, and irradiation behavior, which led to the selection of UO_2 as the fuel dispersant, B_4C as the burnout poison, and austenitic stainless steel as the cladding and matrix material, are reviewed.

The main features of the component engineered for service in power-producing reactors of compact-core design and high-performance characteristics are described. Highly enriched fuel in the form of a refractory oxide is dispersed in a metallic matrix to maximize the heat-transfer surface available for each gram of U-235. It is contained in a stainless steel jacket to afford corrosion protection

and retain the highly poisonous by-products of fission. The use of a burnout poison to facilitate control and prolong the life of the heavy-investment fuel component is discussed. Specifications covering the material, dimensional, thermal, and nuclear characteristics of the product are tabulated.

The fabricational procedures developed and adopted for manufacturing the component are fully presented. This includes incorporation of the UO_2 and B_4C into stainless steel compacts by powder-metallurgy techniques, methods for preparing composite fuel plates by roll cladding, and assembly and joining the thin plates into an integral unit by brazing with a nickel-base alloy. The fabricational problems associated with composition, chemical stability, homogeneity, fragmentation of the oxide and carbide particles as well as sensitization, bond integrity and the braze-joint design are discussed in detail. Quality control measures adopted to produce components within dimensional tolerance on a pilot-plant basis are described.

These long-life fuel components are inexpensive to produce and their performance to date in the environment of pressurized-water and organic media has been excellent. The irradiation performance of the SS-UO_2 materials combination under various degrees of burn-up as well as pertinent mechanical-property data are presented. A cost analysis is made on the over-all fuel cycle.

Preparation of Zirconium-Base Dispersion Fuels: A. P. Beard and R. N. Honeyman, General Electric Co.

In order to develop a better understanding of the various parameters that influence the irradiation behavior of reactor fuels, the authors have started a program that is concerned with zirconium containing various dispersed particles of fissionable materials such as uranium dioxide, uranium monocarbide, uranium, and the δ phase of the zirconium-uranium alloy. This type of reactor fuel, based on the dispersion concept, has been discussed in other publications[1, 2] and, therefore, need not be considered in detail here.

The present paper described the techniques used in making cylindrical irradiation samples of dispersion-type alloys. These techniques involve the preparation of high-quality zirconium alloy powders, preparation of spherical particles of fissile materials, and final consolidation of these two types of materials into samples for irradiation tests. Metallographic examination and other data on the fuel materials are given.

[1] D. W. White, A. P. Beard, and A. H. Willis: *Irradiation Behavior of Dispersion Fuels*, USAEC—KAPL-1909, 1958.

[2] C. E. Weber and H. H. Hinch: *Dispersion-Type Fuel Elements*, International Conference on the Peaceful Uses of Atomic Energy, Paper No. P.561, 1955.

Fabrication and Properties of Uranium-Zirconium Hydride Fuel Elements for Triga Reactors: W. P. Wallace, M. T. Simnad, and B. Turovlin, General Atomic Division of General Dynamics Corp.

The melting, casting, extrusion and machining of 8 wt pct uranium and 92 wt pct zirconium alloy are described; the assembly of the hydrided alloy into a fuel element is described.

The fabrication of the uranium-zirconium hydride fuel materials was accomplished with exceptionally high yields, resulting in relatively inexpensive fuel elements.

It was found that the use of homogeneous mixture of the fuel and the zirconium hydride moderator in the reactor resulted in a prompt negative temperature coefficient, thus enhancing the safety of the reactor.

The physical, chemical and mechanical properties of zirconium hydride and uranium-zirconium-hydride have been measured. In addition to the prompt negative temperature coefficient, these hydrides have excellent corrosion resistance in water, good thermal shock resistance and dimensional stability upon thermal cycling and nuclear irradiation.

2:00 to 5:00 pm, Lorenzo Carter

Symposium on Metal Base Fuels and Jacket Components

(Sponsored by the Nuclear Metallurgy Committee)

F. G. Foote and A. R. Matheson, Chairmen

Silicon-Modified Uranium-Aluminum Alloys for Foreign Reactor Applications: W. C. Thurber and R. J. Beaver, Oak Ridge National Laboratory.

The addition of small amounts of silicon to uranium-aluminum alloys suppresses the formation of UAl_4 producing striking changes in the fabrication qualities of the fuel material. The effects of silicon additions on uranium-aluminum alloys in the range of compositions (40-50 wt pct U) required for applications where the U-235 isotopic enrichment is limited to 20 pct are discussed in terms of casting, billet rolling, and composite fuel-plate fabrication. Particular attention is directed toward the control of the *dog-bone* end effects in roll-bonded fuel plates and component assembly problems peculiar to the novel materials combinations employed. Data are also presented on the mechanical and physical properties of modified uranium-aluminum alloys.

Fabrication of Iron-Aluminum-Chromium Alloy Fuel Plates: F. G. Tate, J. Neri, and Blake King, The Martin Co.

Briefly discussed are the characteristics (oxidation resistance, moderate cross-section, and adaptability to reprocessing) that recommend Fe-Al base alloys for use as cladding materials for gas-cooled core components, and the metallurgical peculiarities (brittleness, joining difficulties, and marginal hot strength) that have limited their use in the past. The properties of a newly-developed Fe-Al base alloy (7½ wt pct Al, 5 wt pct Cr, 1 wt pct Cb, ½ wt pct Ti, rem. Fe) in which the deficiencies of older materials have been largely eliminated are summarized.

Exploratory studies involving the fabrication by hot-roll bonding of dummy fuel elements are described; this work consisted of bonding the alloy described above to itself, to a 302B stainless steel—UO_2 cermet, and to a 0.20 wt pct C steel—Al_2O_3 cermet. Steps in assembling the elements, using a modified picture frame technique, are covered briefly. Methods for removing surface oxides from element components are discussed; it is concluded that mechanical abrasion is most satisfactory. Edge welding of assemblies before rolling them is recommended to avoid oxidation of interfaces. The development of hot-rolling procedures capable of insuring complete bonding of components is described; rolling and heat-treatment schedules are presented in tabular form. Photomicrographs illustrating the recrystallization bonds obtained between core and clad and in the dead-end portions of elements are included.

A moderate amount of data is presented on the preparation of Fe-Al base matrix materials, using powder metallurgical techniques. Comparisons are made between methods of obtaining powdered alloys (elemental powders, master alloys, and other techniques.) Pressures and sintering temperatures employed in forming compacts are discussed. Also covered is the cold rolling of the sintered compacts. The bend ductility and oxidation resistance of the rolled strips is correlated with their metallurgical histories. Test results, photographs and photomicrographs are included.

Fabrication of Zircaloy-2 Clad Uranium-12 Wt Pct Molybdenum Fuel Rods: J. G. Goodwin, R. W. Tombaugh, E. L. Richards, and F. R. Lorenz, Westinghouse Electric Corp.

During the initial development of fuel elements for the PWR, the use of clad metallic-fuel rods was investigated. Design criteria were that the fuel and cladding must be metallurgically bonded for proper heat transfer, and the fuel, cladding, and diffusion zone between the fuel and cladding must be corrosion resistant. U-12 wt pct Mo was selected as the fuel material because it had shown exceptional corrosion resistance for a uranium-rich alloy; Zircaloy-2 was chosen as the cladding material because of its excellent corrosion resistance and low thermal neutron cross section. Coextrusion of the fuel and cladding alloys was the method selected to produce these cylindrical fuel elements. The metallurgical bonding of the fuel and cladding was accomplished by placing a right-circular cylinder of the fuel alloy in a tubular section of Zircaloy-2, encasing these components in a steel jacket, and extruding the assembly at an elevated temperature. The extruded rods were reduced to final size by cold drawing and were made corrosion resistant by etching 0.004 in. from the rod diameter. Stock for fuel components was extruded from duplex cast U-12 wt pct Mo ingots 4 in. in diameter and weighing 60 lb. Wrought fuel was found to be superior to cast fuel because: (1) the billet assemblies utilizing wrought fuel did not require as much extrusion pressure as did assemblies with cast fuel, and because (2) the elements produced from wrought fuel were more dimensionally uniform than those produced from cast fuel because of the more uniform grain size of the wrought material. The Zircaloy-2 cladding components were machined from cups which had been produced by the back extrusion of bar stock. The Ti-Namel steel assembly jackets were made by spinning. The fuel and cladding were assembled into extrusion billets by inserting them in the steel jackets with several accessory components and then sealing the jackets by welding in an inert-gas filled chamber. Fuel rods were fabricated by heating the assembled billets for 15 min at 1635°F in an 85 pct $BaCl_2$—15 pct NaCl salt bath and extruding to 0.437-in. or 0.500-in. diam rods. The steel jackets were removed from the extruded rods by pickling in an aqueous 50 pct

HNO_3 solution. The rods were finished by cold drawing to 0.304-in. diam and etching to the final size of 0.300-in. diam. Dimensional uniformity of the fuel rods was aided by maintaining a temperature control of ±5°F and a uniform billet loading time during extrusion. Front end defects associated with coextrusions were reduced from an average of 16 in. to 5 in. by the use of a separate steel front plug. The dimensional requirements for the finished element were a fuel diameter of 0.240 ±0.005 in. with local variations not to exceed ±0.009 in. from the nominal. A statistical analysis of the fuel diameter data from a group of fuel rods produced from 15 billets showed the average fuel diameter to be 0.2360 in. The 95 pct confidence limits for the process were 0.2345 in. to 0.2366 in.; the 99.9 pct confidence limits were 0.2349 in. to 0.2371 in. Statistical calculations showed that 91.6 pct of the individual measurements met the specification for local variations.

Manufacture of EBR-I, Mark III Fuel and Blanket Elements: R. A. Noland, N. J. Carson, C. C. Stone, F. D. McCuaig, and R. E. Macherey, Argonne National Laboratory.

The fuel elements and blanket elements for the EBR-1, Mark III core loading are round rods nominally 0.403 in. ±0.001 in. diameter by 21.750 in. long. Both types are identical in external appearance and size. The uranium-bearing section is 19.812 in. long. This zone is a single section of normal uranium in the blanket rods. Fuel rods contain an 8.500 in. central section (approximately) of uranium enriched to 92.5 pct U^{235} flanked at each end by normal uranium sections. Solid Zircaloy 2 end caps are at the terminal ends of both types. The rods were made of lengths of 2 wt pct zirconium, uranium, uranium-zirconium alloy clad with a 20 mil jacket of Zircaloy 2 by coextruding the uranium alloy billets sealed in Zircaloy 2 cans. To circumvent the end effects normally encountered in coextrusion and to minimize the number of billets required, billets of a volume sufficient to provide a number of fuel blanket elements per extruded length were used. The long rods were next cut into shorter lengths appropriate for assembly into either fuel or blanket rods. These were then assembled with the Zircaloy 2 end caps and/or fuel sections and the sections were joined at the jackets by tungsten inert gas welding. To provide mechanical strength to the welded joints, the sections were next bonded throughout the cross section at each joint interface by fusing (by induction heating) the uranium alloy to the Zircaloy 2 end fittings and disc separators. Each completed rod is provided with three longitudinal spacing ribs, fastened at 120° intervals around the periphery of the jacket. The ribs, in the form of 0.056 in. diam zirconium wire, were automatically spot welded in place, all three ribs being fastened in a single set-up. The welding equipment necessary for joining the rod sections and for spot welding the spacer ribs in place were specifically conceived and built at ANL for this work.

Bonding of Aluminum With Elemental Silicon: R. A. Noland and D. E. Walker, Argonne National Laboratory.

A pressure-bonding process using elemental silicon powder for joining aluminum and a number of its alloys is described. The method utilizes the solid phase reaction at elevated temperatures between silicon powder and aluminum to produce aluminum-silicon eutectic alloy in situ. No flux is used; the interfering oxide film is circumvented by puncturing it by the sharp, angular silicon particles which diffuse at the puncture points into the base metal. The eutectic alloy thus formed undermines the oxide and both are forced out of the joint by the applied pressure.

This process is carried out by first coating with silicon powder one face of the sections to be joined or bonded. The sections are then assembled, and pressed together in press-mounted dies maintained at 600°C until the work reaches the temperature of the dies. After having been at temperature a short period (1 min average) the work is cooled under pressure to below 550°C, the press is opened, and the work removed. Joints are strong, continuous, and sound, and the process is reproducible over hundreds of samples. Little or no aluminum-silicon eutectic remains in the joint, the excess being squeezed out during hot pressing.

To date the method has been used for producing the Borax IV fuel elements, and for bonding the Al-1 wt pct Ni (X-8001) cladding to the aluminum-uranium-nickel (17.5 wt pct U-2 wt pct Ni) alloy fuel cores in the ALPR fuel elements. The latter are flat plate elements, 0.120 in. thick x 4.655 in. wide x 27.815 in. long, and are intended to operate without replacement for long periods in high purity water at 300 psia and 417°F.

Alternate Bonding Techniques for Fuel Element Components: F. L. Orrell and H. R. Hoge, Westinghouse Electric Corp.

Satisfactory bonds between fuel and cladding components have been produced by a number of ways other than the traditional roll bonding processes. The alternate bonding techniques considered in this paper are pressure bonding and diffusion bonding. The bonding parameters, equipment requirements, component design and product quality are reviewed and evaluated.

WEDNESDAY, OCTOBER 29

Fuel Element Closures: J. E. Minor and S. H. Bush, General Electric Co.

The closure on a fuel element is one of the most critical items in the fabrication of fuel components. Such closures must minimize coolant penetration, be as corrosion resistant as the clad, suffer little or no loss in necessary mechanical and physical properties, and where possible, be made by an inexpensive and simple process that must be reproducible.

The development and behavior of several types of closures prepared and tested during stages of experimental fuel element design in the Hanford Laboratories are described. Examples of types of closures are: Heliarc welding on aluminum, cold closure, hot press closure, electron gun welding on unbonded and bonded aluminum clad elements, welds on unbonded UO_2 elements clad in Zircaloy, electron gun welds on coextruded uranium clad with Zircaloy, integral end closures produced by coextrusion, closures on aluminum-clad Pu-Al elements produced by roll bonding, closures on Zircaloy-clad Pu-Al elements, and welds on stainless steel-clad metallic elements.

The optimum closure conditions, behavior during destructive testing, non-destructive tests results, and corrosion test data are discussed.

2:00 to 5:00 pm, Ballroom

Symposium on
Metallurgy of Columbium and Its Alloys

(Sponsored by the Refractory Metals Committee in Conjunction With the High-Temperature Alloys Committee)

R. W. Fountain and R. C. Nelson, Chairmen

Some Physical and Mechanical Properties of Columbium and Its Alloys: R. T. Begley and L. L. France, Westinghouse Electric Corp.

Some Effects of Alloying on the Strength Properties of Columbium at Elevated Temperatures: G. D. Gemmell, E. I. du Pont de Nemours and Co., Inc.

Properties of Some Columbium Alloys: R. G. Frank, General Electric Co.

Properties of the Ternary Alloy Cb-10 Per Cent Ti-10 Per Cent Mo: A. H. Grobe, Thompson Products, Inc., and H. B. Hix, E. I. du Pont de Nemours and Co., Inc.

Oxidation Behavior of a Columbium-Zirconium Alloy: G. M. Gordon, R. Speiser, and J. W. Spretnak, Ohio State University.

Hot Hardness Measurements of Some Columbium-Base Alloys: A. L. Eiss, L. Sama, and H. P. Kling, Sylvania-Corning Nuclear Corp.

Mechanical Properties and Oxidation Resistance of Columbium-Base Alloys: F. R. Schwartzberg, D. N. Williams and R. I. Jaffee, Battelle Memorial Institute.

2:00 to 5:00 pm, Oak Room

Symposium on
Electrical and Magnetic Metals

(Sponsored by the Electrical and Magnetic Metals Committee)

L. C. Hicks and G. W. Wiener, Chairmen

Magnetic Methods in Metallurgy: Anthony Arrott, Ford Motor Co.

Physical Metallurgy of Magnetic Materials: J. J. Becker, General Electric Co.

Applications of Magnetic Materials: M. F. Littmann, Armco Steel Corp.

The Heusler Alloys: F. A. Hames, Queens University, Kingston, Ontario.

2:00 to 5:00 pm, Embassy Room

Transformations

(Session Based on Submission of Research Abstracts)

A. R. Troiano and D. S. Lieberman, Chairmen

Correlation of Transformation Behavior With Mechanical Properties of Several Titanium-Base Alloys: A. J. Griest, J. R. Doig, and P. D. Frost, Battelle Memorial Institute.

Hardness, tensile, and X-ray diffraction data were compiled to follow the course of aging in the nominal alloys Ti-8Mn, Ti-8Mn-2Al, Ti-4Mn-4Al, Ti-6Al-4V, and Ti-4Fe. The maximum strength obtained on aging increased with increasing solution temperature. For the titanium-manganese and titanium-manganese-aluminum alloys, the specimens as-quenched for the alpha-beta field were ductile. However, after aging for short times at 800 to 900°F they became brittle. Omega phase patterns at this time were strong for the Ti-8Mn alloy, weaker and more diffuse for the Ti-8Mn-2Al alloy, and were not detected positively for the Ti-4Al-4Mn specimens. This confirms that aluminum suppresses the formation of omega phase. The Ti-4Fe alloy exhibited maximum strength and brittleness in the beta-quenched condition. Compound formation was observed after prolonged aging.

It was possible, through suitable aging treatments, to eliminate the omega phase, restore the ductility, and maintain relatively high strengths in these alloys when quenched from the alpha-beta field.

Omega was not observed on aging of the Ti-6Al-4V alloy. However, in addition to alpha prime, a second transition phase, designated alpha double prime, was observed when this alloy was quenched from 1800°F. Upon aging, the transition phases apparently transform to beta and alpha.

Lattice Stability of Metals—I. Titanium and Zirconium: Larry Kaufman, Manufacturing Laboratories, Inc.

The difference in free energy between the HCP (α) and BCC (β) phases of Ti and Zr has been calculated between 0 and 2000°K by using available thermodynamic data. These calculations take into account the lattice and electronic contributions to $\Delta F_{Ti}^{\alpha\rightarrow\beta}$ and $\Delta F_{Zr}^{\alpha\rightarrow\beta}$ and permit estimates to be made of the Debye θ, melting point, and heat of fusion of the HCP and BCC modifications of these metals, as well as the difference in zero point energy between α and β phases. The values of $\Delta F_{Ti}^{\alpha\rightarrow\beta}$ are in good agreement with those determined experimentally by McQuillan.

The results for $\Delta F_{Ti}^{\alpha\rightarrow\beta}$ and $\Delta F_{Zr}^{\alpha\rightarrow\beta}$ have been used to derive the thermodynamics of the Ti-Zr system, from which it is possible to compute the chemical driving force, $\Delta F^{\alpha\rightarrow\beta}|_{M_s}$, for the marten-

stitic transformations which take place in Ti-Zr alloys. Approximate calculations of $\Delta F^{\alpha \rightarrow \beta}{}_{M_s}$ have also been carried out for several additional titanium-base alloy systems. The results indicate that the chemical driving force for martensitic transformations in titanium-base alloys is considerably less than what has been encountered in steels. These results may be interpreted by considering the crystallography of the transformations in titanium-base alloys.

Effects of Composition on Transformations in Titanium-Chromium Alloys: H. I. Aaronson, Ford Motor Co., W. B. Triplett, Carnegie Institute of Technology, and G. M. Andes, E. I. du Pont de Nemours and Co., Inc.

Effects of composition on the morphology and mechanism of the proeutectoid alpha and the eutectoid reactions in hypoeutectoid titanium-chromium alloys have been examined by comparing the structures developed in an iodide-base Ti-10.8 pct Cr alloy with those previously studied[1] in an iodide-base Ti-7.22 pct Cr alloy.

The morphologies of proeutectoid alpha previously observed in the 7.22 pct Cr alloy were again found in the 10.8 pct Cr alloy. The only effect of the increase in chromium content is to reduce from 50 to 75°C the temperature at which those alpha structures whose formation or shape is temperature-sensitive will develop. These reductions average somewhat larger than the corresponding decrease in the temperature of the beta alpha + beta equilibrium curve, from between 745° and 750°C in Ti-7.22 pct Cr to between 690° and 695°C in Ti-10.8 pct Cr.

The mechanism of the eutectoid reaction is the same in both alloys: $TiCr_2$ and alpha precipitate successively from beta in nonlamellar form. The higher rate of the eutectoid reaction in the 10.8 pct Cr alloy has been utilized to demonstrate that the beta phase can be completely decomposed at temperatures at least as high as 625°C, a temperature only 20 to 25°C below the eutectoid temperature in this alloy. Failure of this result to be obtained in earlier investigations played a major role in the development of the hypothesis that the eutectoid temperature of the titanium-chromium system lies at about 500°C[2], rather than in the range of temperatures, 650° to 700°C, previously reported.

Criticisms which have been made of the Vycor capsule method of heat treating titanium alloy specimens[2] will be discussed in some detail.

[1] H. I. Aaronson, W. B. Triplett, and G. M. Andes: AIME *Trans.*, 1957, vol. 209, p. 1227.
[2] A. D. McQuillan and M. K. McQuillan: Titanium, Academic Press, Inc., New York, 1956.

Effects of Aluminum on Morphology and Kinetics of Alpha Formation in a Ti-10 Pct. Mo Alloy: H. I. Aaronson, Ford Motor Co., W. B. Triplett, Carnegie Institute of Technology, and G. M. Andes, E. I. du Pont de Nemours and Co., Inc.

The beta → alpha transformation has been investigated in Ti-10 pct Mo and Ti-10 pct Mo-3.5 pct Al alloys.

The only effect of aluminum upon the morphology of alpha is to raise from 50 to 75°C the temperature at which temperature-sensitive alpha structures are reproduced. This displacement averages slightly less than the increase of about 70°C which this amount of aluminum effects in the transus temperature.

In general agreement with the results of Kessler and Hansen[1], aluminum displaces the TTT-curves for both the initiation and the completion of transformation to shorter times. At the temperatures at which *black plates* (long, thin, dark-etching, will-formed crystals) replace *normal alpha* plates, however, the curves for the initiation of transformation are abruptly displaced to longer times in both alloys and the curve for completion is displaced to shorter times in the ternary alloy.

The rate of lengthening of sideplates is higher in the ternary alloy throughout the temperature range studied. As in the case of the TTT-curves, the rate of lengthening increases discontinuously when *black plates* replace *normal alpha* plates. Qualitative observations indicate that the addition of aluminum also increases the rate of nucleation of alpha.

The effects of aluminum on the kinetics of alpha formation can be tentatively explained in terms of the increase in the transus temperature that this element produces. At a given temperature, the higher ratios of the concentration gradients in unreacted beta to the concentration differences across the interphase boundary which result from the change in phase diagram geometry will account for the higher growth rates in the ternary alloy. The larger undercooling in the ternary alloy during transformation at a given temperature, resulting in a higher volume free energy change, should be a major factor in the increase in the rate of nucleation of alpha that aluminum engenders.

[1] H. D. Kessler and M. Hansen: ASM *Trans.*, 1954, vol. 46, p. 587.

Relation Between Beta Grain Size and Ductility of High-Strength Alpha-Beta Titanium Alloys: A. J. Griest, A. P. Young, and P. D. Frost, Battelle Memorial Institute.

A study was made of the effect of beta grain size on the tensile ductility of three alpha-beta titanium alloys (Ti-6Al-4V, Ti-4Al-4Mn, and Ti-16V-2.5Al) heat-treated to strengths in the range 165,000 to 180,000 psi ultimate. It was concluded that the primary cause of beta embrittlement is the large grain size that is so rapidly developed in many alpha-beta titanium alloys when heated into the beta field. It was also found that grain-boundary alpha and acicular intragranular alpha phase in the microstructure are not necessarily detrimental to the tensile ductility if the prior beta grain size is sufficiently fine. One alloy (Ti-16V-2.5Al) showed a much lower rate of beta grain growth than most alpha-beta alloys. This observation gives promise that heat-treatable, high-strength, alpha-beta alloys can be developed which can be forged in the beta field without serious impairment of the tensile ductility.

The $\alpha \rightarrow \beta$ Transformation in Zircaloy-2: Josef Intrater, Materials Research Corp.

The temperature limits of the ($\alpha + \beta$) phase region in Zircaloy-2 were determined dilatometrically as a function of heating and cooling rates.

The $\alpha + \beta$ transformation temperature limits in vacuum-melted Zircaloy-2 were found to be between 815 to 830°C to between 975 to 995°C on heating and from between 960 to 930°C to between 785 and 770°C on cooling. These temperature limits are a function of the rate of heating and cooling.

1. The temperature of $\alpha \rightarrow \alpha + \beta$ transformation increases 5 to 15°C with increasing rate of heating.
2. The temperature of $\beta \rightarrow \alpha + \beta$ transformation decreases 20 to 30°C with increasing rate of cooling.

There is no significant dependence of the transformation temperature on the prior thermal history of the material.

Within the $\alpha + \beta$ region there is an additional inflection point. This plateau in the thermal expansion curve on heating and cooling is the result of a reaction involving Fe, Ni, and Cr. This reaction can be suppressed by increasing the rate of heating, which indicates that it is a diffusion-controlled process.

Metallographic and dilatometric studies indicate two modes of transformation of $\beta \rightarrow \alpha$:

(a) Martensitic.
(b) Nucleation and Growth.

Orientation of Single Martensite Plates in Austenite: Henry M. Otte, Rias, Inc. (Research Institute for Advanced Study).

Using Laue back reflexion techniques with an X-ray micro-beam 10 to 50μ in diameter the orientation of single plates of martensite (in the austenite matrix) were determined. The quality of the photographs obtained was greatly dependent on the composition of the alloy. From good photographs of austenite and martensite the orientation relationship could be established to quite a high degree of precision, and was expressed most concisely as an axis and angle of rotation rather than as the parallelism of planes and directions that are in fact not truly parallel.

The results were compared with the single equally precise measurement made by Greninger and Troiano (1941) and with the more approximate observations of Kurdjumov and Sachs, and of Nishiyama.

By determining the correct variant of a direction in the habit plane the results were analysed and interpreted in terms of the current phenomenological theories of the martensite transformation. The slip system of the "inhomogeneous part" of the total deformation accompanying the transformation was calculated. The results suggested that the slip system is that which is characteristic of BCC metals. The possibility of faulting associated with slip is considered in connection with the anomalous X-ray diffraction line broadening and diffuse Laue spots, and has special interest in BCT martensite.

Order-Disorder Transformations in Iron-Aluminum Alloys: H. J. McQueen and G. C. Kuczynski, University of Notre Dame.

The portion of the equilibrium diagram between 20 and 34 at. pct Al in iron was revised on the basis of dilatometric data. It was found that alloys below 23 at. pct Al transform from disordered solution to ordered Fe_3Al structure; whereas those above 23 at. pct Al transform first to FeAl structure, and then to Fe_3Al. The Curie points of ordered and disordered alloys were measured.

The isothermal ordering rates for the 25 at. pct Al alloy quenched from the disordered region and from the FeAl region, were meas-

ured at temperatures between 200° and 500°C. The results are approximately the same for each disordering temperature and indicate that the transformation is one of nucleation and growth.

The degree of order at different temperatures was calculated from the final minimum resistivity, obtained after ordering for long times at these temperatures.

Measurement of Grain Continuity in Two-Phase Alloys: Dr. J. Gurland, Brown University.

The average contact area between grains of one phase in multiphase alloys can be obtained by metallographic analysis according to the principles developed by Smith and Guttman[1] and Fullman.[2] In addition, for uniform spherical grains, the average number of contacts and the area of contiguity per contact can be determined. Relations between the area of contact, the dihedral angle, and the mean free path of uniform spherical grains are derived and are compared to the measured quantities found in a number of cemented carbide and α-β brass samples.

[1] C. S. Smith and L. Guttman: *AIME Trans.*, vol. 197, 1953, p. 81.
[2] R. L. Fullman: *AIME Trans.*, vol. 197, 1953, p. 447.

Thursday, October 30

9:00 am to 12m, Ballroom

Symposium on
Mechanical Properties and Effect of Interstitials

(Sponsored by the Refractory Metals Committee in Conjunction With the High-Temperature Alloys Committee)

N. J. Grant and J. H. Bechtold, Chairmen

Dislocations in Molybdenum: R. D. Forest and D. W. Bainbridge, Colorado School of Mines.

Effect of Variations in Carbon and Oxygen Contents on the Properties of Wrought Molybdenum-Titanium Alloys: M. Semchyshen and R. Q. Barr, American Metal Climax, Inc.

Strengthening by Carbide Dispersion in Molybdenum Alloys: W. H. Chang, General Electric Co.

Deoxidation and Denitrification Studies of Chromium and the Effect on Low-Temperature Properties: H. L. Levingston and N. J. Grant, Massachusetts Institute of Technology.

Influence of Interstitial Content and Processing Variables on the Mechanical Properties of Columbium Metal: A. L. Mincher and W. F. Sheely, Electro Metallurgical Co., Div. of Union Carbide Corp.

High-Temperature Tensile Properties of Molybdenum and Tungsten: R. W. Hall and P. F. Sikora, National Advisory Committee for Aeronautics, Lewis Flight Propulsion Laboratories.

9:00 am to 12m, Embassy Room

Diffusion

(Session Based on Submission of Research Abstracts)

F. R. Foote and John Zambrow, Chairmen

Layer Growth During Inter-Diffusion in the Aluminum-Nickel Alloy System: L. S. Castleman and L. L. Seigle, Sylvania Electric Products Inc.

The kinetics of growth of intermediate phase layers in the aluminum-nickel system has been explored in diffusion couples annealed in the temperature range 400 to 625°C for times up to 340 hr and under pressures up to 5 tsi. It has been found that all phases appear in the interdiffusion zone at 600°C that are thermodynamically stable at the diffusion temperature; these phases are the $NiAl_3$ (θ), Ni_2Al_3 (γ_1), NiAl (δ), and Ni_2Al (ϵ) intermetallic compounds. The rate controlling factor affecting the kinetics of growth of the γ phase in the early stages is not yet clear; after a minimum thickness of 0.025 to 0.030 mm is reached, however, volume diffusion controls layer growth. It is estimated that the chemical diffusion coefficient is 9.1×10^{-10} sq cm per sec and that the heat of activation for diffusion is 31,000 cal per mol. An applied pressure of 5 tsi reduces the diffusion rate by about 27 pct. Volume diffusion controls the growth kinetics of the β phase after a minimum thickness of 0.040 mm is reached; it is estimated that the 600°C diffusion coefficient is about 1.8×10^{-11} sq cm per sec and that the heat of activation is approximately 27,000 cal per mol. Tentatively, it appears that pressure affects the growth of the β phase much less than the γ phase. The growth kinetics of the δ and ϵ phases also appear to be volume diffusion controlled.

Theoretical Calculation of the Relaxation of Atoms Surrounding a Vacancy in Cubic Metals From Morse-Type Potentials: L. A. Girifalco and V. G. Weizer, National Advisory Committee for Aeronautics.

Both of the models used in recent calculations of the lattice deformation about a vacancy contain defects which tend to hinder their validity as models. The inverse-power potential function model used by Kanzaki, Hall, Girifalco, and Streetman in their calculations results in an infinite energy of cohesion in the case of the alkali metals. It is also doubtful that the attractive forces in Tewordt's Born-Mayer repulsive potential model may be validly neglected. Thus the use of the Morse potential function model, which has neither of these defects, is warranted.

Calculation of the relaxation configurations and energies was performed using the successive approximations technique. For the face-centered metals treated, Pb, Ni, Cu, and Ca, it was found that the first and second nearest neighbors relax the following amounts: Pb: +1.4 pct, —.85 pct, Ni: +2.1 pct, —.78 pct, Cu: +2.2 pct, —.79 pct and Ca: +2.7 pct, —.81 pct. The negative values refer to motion away from the vacancy. The results for the body-centered metals, taking into account the interactions of the third nearest neighbors are: Fe: +6.1 pct, —4.3 pct + 2 pct, Ba + 7.4 pct, — 4.2 pct, + 1 pct, Na: + 8.9 pct, — 3.5 pct, + 7 pct.

For iron, essentially the same results were obtained with the Morse potential as with the inverse power 5-7 potential used by Girifalco and Streetman.

An analysis of the validity of the Morse potential in describing the behavior of metal crystals was made on the basis of theoretical calculations of the equation of state and the elastic constants. This analysis shows that the Morse potential has a greater range of applicability than the other types of potentials commonly used.

Effect of Static Strains on Solid-State Diffusion—A Theoretical Treatment: L. A. Girifalco and H. H. Grimes, National Advisory Committee for Aeronautics.

In view of the important role played by diffusion in many metal applications such as oxidation, creep, rupture, and the annealing of radiation damage, and in view of the wide variety of applications in which materials are under strain, it is highly desirable to have a thorough understanding of the effects of strain on diffusion.

A general theory of solid-state diffusion in strained systems has been developed on a molecular-kinetic basis which predicts that, for static elastic strains, the diffusion coefficient is an exponential function of the lattice parameter. The rate of change of the diffusion

coefficient with strain is explicitly related to the interatomic forces so that the magnitude of the effect can be calculated from interatomic potential theory.

Recent experimentation has indicated that in metals subjected to elastic strains the diffusion coefficient may be doubled and that large hydrostatic pressures (~10,000 atm) can lower the coefficient by an order of magnitude. These data are discussed in the light of the theory presented and are shown to be in substantial agreement with it. In every case for which literature data are available, the diffusion coefficient is found to be an exponential function of the strain. Furthermore, the rate of change of the diffusion coefficient with strain is in agreement with the results to be expected on the basis of interatomic forces.

Effect of Plastic Flow on Self-Diffusion in Silver: A. F. Forestieri and L. A. Girifalco, National Advisory Committee for Aeronautics.

Recently, a theoretical framework has become available that predicts how the diffusion coefficient should depend on plastic flow. The theory is based on the assumption that an excess concentration of vacancies is produced during plastic flow by the dislocation motion. For diffusion by a vacancy mechanism, these excess vacancies enhance the diffusion rate. The equations show that the diffusion rate is a function of the strain rate, the production rate of the vacancies, and the rate at which they anneal.

The experimental work consisted of a measurement of self-diffusion coefficient of silver during compressive strain. The diffusion specimen consisted of a thin plate of radioactive silver sandwiched between two cylinders of normal silver. The specimen was compressed at a constant strain rate during the diffusion run. After completion of a run, the specimen was sectioned normal to the radioactive plate and the diffusion coefficient measured by an autoradiographic technique.

The results show that the diffusion coefficient is a linear function of strain rate for all temperatures at which measurements were made. An analysis of the variation of the diffusion coefficient with temperature for a constant strain rate indicates that, at low temperatures, the vacancy production is temperature independent and probably occurs by a geometric dislocation mechanism. Also, the vacancy anneal process probably takes place by a mechanism in which vacancies diffuse and disappear at sinks such is dislocations and grain boundaries. At higher temperatures, the results indicate that the mechanism is more complex than this simple picture.

Self-Diffusion in Tin Single Crystals: J. D. Meakin and Eric Klokholm, Franklin Institute.

The self-diffusion of tin has been measured in single crystals using a plating and sectioning technique. The diffusivity along the *a* axis has been shown to be about four times greater than along the *c* axis in marked variance with the results of P. Fensham but in general agreement with the value predicted from a vacancy model of diffusion. The activation energy of self diffusion along both axes is of the same order as published values for high-temperature creep of tin, and the results also show reasonable agreement with previous diffusion measurements of indium in tin.

Short Circuit Diffusion: G. T. Murray, Materials Research Corp., and E. S. Machlin, Columbia University.

Utilizing the surface accumulation technique, experiments were conducted to determine the short circuit diffusivities of silver and nickel along dislocations, introduced by bending, and grain boundaries in silver. The self-diffusivity of silver along grain boundaries was in fair agreement with that of previous investigators. The discrepancy could be explained on the basis of material lost from the short circuit path to the lattice proper. The dislocation diffusivity for silver self-diffusion was too small to be measured by techniques of the sensitivity employed here. It was concluded that this diffusivity was less than that of the grain boundary self-diffusion.

It was found that the grain boundaries in silver acted as short circuit paths for the diffusion of nickel atoms. Assuming that the diffusivity of nickel along the silver grain boundary is approximately that of silver grain boundary self-diffusion, it was estimated that the solubility of nickel in the grain boundary is of the order of 50 at. pct as compared to 0.02 at. pct for the solubility of nickel in the bulk silver. The dislocation diffusivity of nickel in silver was also too small to be measured and is thus less than the grain boundary diffusivity.

Formation of Surface Pits by the Condensation of Vacancies: P. E. Doherty and R. S. Davis, Harvard University.

Small surface pits are observed to form on electropolished surfaces of aluminum single crystals during cooling from elevated temperatures. The amount of cooling required before the pits begin to form increases exponentially as the holding temperature decreases. The formation of these pits during cooling is attributed to the condensation of vacancies at specific sites on the free surface.

This hypothesis is supported by the following observations:

1. Pits do not form in the vicinity of small- or large-angle grain boundaries.
2. The width of the pit-free region at the boundaries increases as the rate of cooling decreases.
3. If a few pits are produced on the surface by chemical etching and the specimen is cycled, new pits will not form in a considerable area around each previously existing pit.
4. If a specimen is deformed plastically and then heated, the decrease in temperature required for the formation of pits is markedly increased over that required before deformation.

Stress-Induced Ordering Internal Friction of Iron-Aluminum Alloys: J. C. Shyne, Ford Motor Co., and M. J. Sinnett, University of Michigan.

Mechanical damping measurements were made on alloys of iron and aluminum containing up to 31.3 at. pct Al. The stress-induced ordering internal friction of these alloys was examined by means of a torsion pendulum-type apparatus.

The relaxation strength of the stress-induced ordering relaxation mechanism was very small below 10 at. pct Al but increased rapidly from 10 to 19 pct at. pct Al. Beyond 19 at. pct the relaxation strength was decreased by long-range order, which was most nearly perfect at 25 at. pct Al. At that composition, Fe_3Al, the relaxation strength reached a minimum and increased slightly as the Al content was further increased to 31.3 at. pct. It was concluded that a high degree of short-range order existed at the lower Al contents and that the Fe_3Al superlattice was not perfect because of thermal disorder.

The activation energy for the relaxation process was obtained by observing the relationship between oscillatory frequency and the internal friction peak temperature. In a disordered 12.8 at. pct Al alloy the activation energy was observed to be 59.8 Kcal per mole, while in a 27.1 at. pct Al alloy having the Fe_3Al ordered structure the activation energy was 58.6 Kcal per mole. This similarity of activation energies suggests that the relaxation mechanism was the same with and without long-range order.

In some alloys an interfering damping mechanism was encountered. This appeared to be magnetoelastic static hysteresis and was eliminated or minimized by the application to the specimens of static axial loads of 1000 psi or more.

Interstitial Stress Relaxation in Ternary Alloy Systems: D. Gupta, University of Illinois, and Sheldon Weinig, Materials Research Corp.

The results of interstitial stress relaxation studies in hexagonal systems has been somewhat controversial. A calculation indicated that the only possible interstitial sites in the hexagonal close-packed lattice were symmetric, and hence no relaxation was possible.[1] In contrast Pratt, Bratina, and Chalmers found that the introduction of oxygen into the α-Ti lattice caused the appearance of a peak in the internal friction spectrum.[2] In this investigation the authors studied ternary systems of Ti-O-X.

Binary alloys of *superpurity* Ti infused with oxygen revealed no internal friction peak attributable to an interstitial stress relaxation. However, as little as 0.1 at. pct of a substitutional alloying addition in conjunction with the interstitial element caused the appearance of an internal friction maxima. Ternaries of Ti-V-O and Ti-Zr-O both caused the manifestation of the *oxygen* peak. Zr has a positive size factor and V a negative size factor with Ti.

In order to eliminate the possibility of the stress relaxation being caused by a localized precipitate, an alloy of very large terminal solid solubility was tested. A peak was observed in the spectrum of this Ti-Al-O alloy and hence eliminated the possibility that the peak is due to a precipitate.

It was suggested that the mechanism of this relaxation observed in ternary alloys was due to substitutional solute atom distortion of the lattice which would allow sufficient anisotropy for the stress relaxation of the oxygen atoms to occur. Additional support of this suggested mechanism was found in the examination of the Ti-Cb-O system where Cb has a zero size factor with Ti and a limited terminal solid solubility for Cb and O in the Ti-rich corner of the ternary diagram. An almost negligible peak was observed.

It is suggested that the mechanism whereby the substitutional solute atoms enhance the appearance of the interstitial peak is as follows: The out-of-size substitutional atom causes a localized distortion of the lattice that effectively destroys the isotropic nature of the octahedral interstitial sites. Hence, one site becomes energetically favorable to another upon the application of an external stress. This causes a stress-induced interstitial relaxation phenomenon which is manifested by the appearance of an internal friction peak.

[1] B. Bovarnick: Interstitial Holes in the Ti-HCP Lattice; 1952, Watertown Arsenal No. WAL 401/122 O.O. Project No. TB 4-15.

[2] J. N. Pratt, W. J. Bratina, and B. Chalmers: *Acta Met.*, vol. 2, 1954, p. 203.

THURSDAY, OCTOBER 30

9:00 am to 12m, English Room

Deformation and Fracture

(Session Based on Submission of Research Abstracts)

C. S. Barrett and R. L. Fleischer, Chairmen

Cause of Cleavage Fractures in Ductile Materials: J. Washburn, A. E. Gorum, and E. R. Parker, University of California.

The relationship between plastic deformation and the initiation of cracks in magnesium oxide crystals has been studied by the dislocation etch-pit technique. The objective of the research was to obtain evidence that would either support or contradict the theories of fracture nucleation based on stress concentrations due to pile-ups of dislocations on intersecting slip planes. MgO was used because only a small amount of plastic deformation occurs prior to cleavage fracture and the distribution of dislocations can be revealed by etching. Small rectangular specimens cleaved from large commercially pure (99.5 pct) MgO were deformed in bending and in tension.

In tension tests cracks leading to fracture frequently formed at the intersection of two active slip bands. The ductility was extremely small; plastic strain at fracture was usually less than 0.1 pct. However the strain in the surface layers when a crystal was deformed in bending was much greater. In many cases plastic strains of more than 20 pct preceded fracture. The stress gradient in a bend specimen appeared to be the important factor. In a thin bend specimen dislocations multiply primarily near the parts of the specimen farthest from the neutral axis. The deformation, therefore, proceeds by motion of dislocations away from the most highly stressed surfaces toward the neutral axis. Large dislocation pile-ups are not likely to occur at the tension surface because all of the dislocations are moving away from that surface. Pile-ups that do occur must be at some distance from the tension surface and are, therefore, less likely to lead to failure. In a tension specimen the uniform stress across the specimen results in heterogeneous nucleation of slip bands. Large pile-ups can occur near any of the surfaces due to intersection of slip bands which originated on the opposite surface.

Grown-in dislocation substructure appeared to play no rule in the plastic deformation or fracture of magnesium oxide.

Deformation Resulting From Grain Boundary Sliding: Hans Brunner and N. J. Grant, Massachusetts Institute of Technology.

This paper is concerned with the determination of equations relating elongation to the amount of shear taking place both along grain boundaries and in slip planes of polycrystalline aggregates during creep. Certain discrepancies with previously used equations are pointed out. Grain boundaries were observed to become serrated during creep, but it is shown that this does not necessarily prevent further grain boundary sliding. Direct observations of subgrain boundary migration lead to the conclusion that this migration facilitates sliding along serrated grain boundaries. It is pointed out that the state of stress at triple points is still unknown.

Measurements of Deformation Resulting From Grain-Boundary Sliding in Aluminum and Aluminum-Magnesium Alloys From 410° to 940°F: Hans Brunner and N. J. Grant, Massachusetts Institute of Technology.

The contribution of grain boundary sliding to total elongation in creep of pure aluminum was determined quantitatively as a function of temperature and solid solution alloying with magnesium. It is shown experimentally that the deformation due to grain boundary sliding is not necessarily a constant fraction of the total elongation during the course of any one test. It is demonstrated that the increased severity of plastic deformation in the immediate vicinity of sliding grain boundaries is the consequence of the serration of the grain boundaries. Direct observation shows that the migration of subgrain boundaries plays a role in the accommodation of grain boundary sliding along serrated grain boundaries as well as in the deformation of the grains.

Preliminary Evaluation of the Silver Chloride-Alumina System as a Means of Studying Fine Particle Strengthening of Solids: T. L. Johnston, R. J. Stokes, and C. H. Li, Minneapolis-Honeywell Regulator Co.

In metals and alloys hardened by the addition of a dispersed phase (e.g., cermets, SAP-type materials) it is difficult experimentally to study the relationship between microstructural parameters and resistance to deformation, fracture, and recovery. To overcome this difficulty, the silver chloride-alumina system has been adopted. Silver chloride has the unique advantage of being ductile and transparent. Furthermore, dislocations can be readily decorated at room temperature.

It has been shown that the chemical stability, bond strength and wettability of the two phases are such that this system has great potential as a medium for studying the principles of fine particle strengthening of solids. Preliminary results show that (a) particle shape has an important bearing on the deformability of cermet-type compacts, and (b) the high-temperature mechanical stability in SAP-type materials is probably due to limitations imposed upon the climb and annihilation of dislocations in the neighborhood of hard particles and not due to the resistance to migration of grain boundaries.

Effect of Liquid Metal Environments on the Fracture Strength of Solid Copper: D. A. Kraai, D. V. Ragone, and E. E. Hucke, University of Michigan.

The variation of fracture strength of solid Cu specimens was investigated as a function of the interfacial energy between the specimen and its liquid metal environment. From considerations of the energy required to propagate a crack in a brittle material previous workers have shown that the fracture stress should be proportional to

$$\sqrt{\gamma_{ib}\left(\sec\frac{\theta}{2}-1\right)}$$

where γ_{ib} is the interfacial grain boundary energy and θ is the grain boundary dihedral angle. The grain boundary dihedral angle was taken as the measure of the relative interfacial energy between the specimen and its environment. The interfacial energy was varied by successive additions of Bi to liquid Pb. The experimental part of this work dealt with establishing: (1) the existence of an effect of interfacial energy on fracture strength; (2) the relative magnitude of the effect; and (3) the approximate validity of the expression given above. It was found that the tensile fracture stress of a copper wire was reduced by the successive addition of bismuth to a lead-bismuth environment. At 500°C for instance, an environment of liquid lead reduced the fracture strength of copper from 11,000 psi to 9,500 psi or 13.5 pct and an environment of 30 pct Pb-70 pct Bi reduced the fracture strength to 7,200 psi or 34.5 pct. The change in fracture stress with changing interfacial energy corresponded approximately to that predicted by the above expression even though some of the assumptions are not necessarily fulfilled.

Temperature Dependence of the Tensile Properties of Face-Centered Cubic Metals: R. P. Carreker, Jr., General Electric Co.

Effect of temperature on the tensile properties of ten face-centered cubic metals is summarized. The data are taken from results previously published by the author augmented by appropriate data from the general literature.

The tensile strengths of annealed, polycrystalline, face-centered cubic metals of nominal purity are virtually independent of past history, including minor impurities and grain size variations.

The shapes of the tensile strength vs temperature curves of these metals are remarkably similar when plotted as a function of the fraction of the absolute melting temperature, T/T_M.

The tensile strength vs T/T_M curves may be superposed to create a common curve by shifts in log (stress) that tend to be linearly related to the melting points of the metals.

Data supporting these generalizations are presented covering the homologous temperature range 0.01 to 0.96.

The temperature dependence of the tensile strength of face-centered metals is characterized by a monotonic decrease with increasing temperature, upon which is superposed a strength contribution due to the interaction of moving dislocations and moving substitutional impurities. The enhanced strength appears near the homologous temperature $T/T_M = 0.5$, consistent with self diffusion data and the rate of straining employed in tensile tests.

Deviations from the above generalizations were observed in aluminum and platinum at temperatures below $T/T_M = 0.2$. These deviations are rationalized on the basis of the narrow widths of the extended dislocation faults between dissociated dislocations in these metals.

The effects of grain size and strain rate are presented for those metals where appropriate data were available.

THURSDAY, OCTOBER 30

Initiation of Tensile Fracture in Ductile Metals: H. C. Rogers, General Electric Co.

Prior investigations into various aspects of the fracture of polycrystalline ductile metals are briefly reviewed. The present investigation differs from the previous ones in that it utilized several experimental approaches to gain a more complete picture of the process of failure.

Tensile specimens of coarse-grained OFHC copper were each deformed at room temperature to a different strain beyond that at which necking began. They were then radiographed to determine the extent of internal cracking before visible failure.

The central portion of each bar containing the neck was removed and sectioned at intervals parallel to the specimen axis. Each section was then metallographically polished and etched.

The sectioning revealed that the initial failure of the copper took place at grain boundaries with the formation of small voids. At the strain at which necking begins there were a few voids at points where three grains intersect (triple points). When the neck was moderately well developed, voids were formed also on grain boundaries lying parallel to the stress axis. Only after local distortion became quite high, were voids nucleated within the grains themselves.

The inner surfaces of the larger voids were replicated and compared under the electron microscope with replicas of fractures of the same copper. Certain portions of the fracture were intergranular; others, transgranular.

Similar work with nickel is also described and the results compared with the copper results. The general problem of the room temperature failure of ductile metals is compared with that of void formation and failure in creep at higher temperature. Both experimental observations and probable mechanism of void formation are discussed.

THURSDAY, OCTOBER 30

Stress Analysis of the Bausch-Type Shear Test: W. L. Phillips, Jr., Dana Young, and W. D. Robertson, Yale University.

An analysis has been carried out of the stress distribution existing in the different modifications of the direct (Bausch) shear test which have been employed to study the deformation of single crystals. With gage lengths that are long, relative to the diameter of the crystal, the maximum longitudinal stress at the surface, σ_m, may be larger than the maximum shear stress, τ_m; and the bending moment also increases with the magnitude of the gage length. There are, therefore, two effects which may add to the recorded strain, bending, and shear on some family of planes other than the one for which the crystal was oriented.

With short gage lengths $\frac{\tau_m}{\sigma_m}$ is greater than unity and the bending moment is relatively small. Both the longitudinal and shear stress are functions of the angle, α, between the crystal axis and the pole of the slip plane. When α is less than 27° the shear stress on the slip plane has a maximum at the center of the crystal; at $\alpha = 27°$ the shear stress is constant across the slip plane; for α greater than 27° the shear stress is a minimum at the center. Thus, it may be anticipated that both critical resolved shear stress and range of easy glide will be dependent on initial orientation as is, in fact, observed in the shear deformation of aluminum and copper single crystals. Furthermore, it appears that the results of the shear test may be compared with the conventional tension test provided that attention is given to the angular dependence of the shear stress distribution.

9:00 am to 12m, Lorenzo Carter

Symposium on Powder Metallurgy

G. L. Bibbins and H. H. Hirsch, Chairmen

High Purity Tantalum: R. F. Rolsten, E. I. du Pont de Nemours and Co.

Iodide tantalum was prepared by the thermal decomposition of tantalum iodide(s) on an indirectly heated quartz surface. The metal was deposited on and easily removed from the quartz surface without contamination. The tantalum deposit was considerably purer with respect to oxygen, nitrogen, and hydrogen than the commercial tantalum sheet from which it was prepared. Typical analyses of the iodide tantalum are 0.006 pct O_2, 0.007 pct N_2, and 0.0004 pct H_2.

The apparatus and experimental conditions used in this investigation are described in some detail. In addition, the solid and gaseous species were removed from the deposition unit and analyzed by chemical and X-ray diffraction techniques. The role played by the various iodides in the deposition process is correlated to the experimental conditions and deposition rate of tantalum.

Oxidation Resistance and Fabricability of Molybdenum-Nickel Dispersion Alloys: E. S. Bartlett, D. N. Williams, and R. I. Jaffee, Battelle Memorial Institute.

The oxidation resistance and fabricability of molybdenum powder metallurgy alloys containing up to 20 wt pct Ni in the form of a fine dispersion were studied. The effects of dispersion distribution and of amount and type (pure nickel or nickel compounds) of additive were considered. A definite improvement in oxidation resistance was observed, but the amount of improvement fell far short of requirements for an oxidation-resistant alloy. Fabricability by hot rolling was limited.

Effect of Sintering Treatment on Electropotential and Strength of Carbonyl Iron: Bennett Bovarnick, Watertown Arsenal.

Despite the expanding interest and investigations of sintering, the need to establish a direct correlation between a physical property and the sintering treatment still exists. The effect of the sintering on changes in surface energy of the powder system is discussed as a promising approach to the correlation. In accordance with Gibbs-Helmholts principles, the electrochemical potential was measured as the equivalent of the energy change with the variation of sintering treatment.

A test system was designed to measure the electrochemical potential of specimens sintered to varying degrees. Specimens of carbonyl iron powder were pressed to four green densities from 5.0 to 6.5 gm per cc and sintered at temperatures from 800° to 1200°C for times of ½ to 8 hr for a total of 40 different treatment conditions. The specimens were tested for electrochemical potential, tensile strength, density, and microstructure.

The electrochemical potential of unsintered, pressed iron powder was found to be 720mv referred to a saturated calomel electrode, and independent of the compacting conditions studied. The electrochemical potential of sintered specimens ranges from a high of 760mv for lightly sintered to a low of 620mv for severely sintered specimens. The corresponding tensile strengths ranged from minima of 10,000 psi to maxima of 30,000 psi.

The electrochemical potential, E, in volts, is related to tensile strength, S, by the expression $E = -6.78 \times 10^{-6} S + 0.830$ with a statistical correlation coefficient of 0.94. A sintering severity parameter, P, was derived in the form $P = t(d_s/d)^{2.7} T^{5.6 - Q/RT}$, where the variables of P are the treatment conditions: relative density (d/d_s), time (t), and temperature (T).

Some Properties and Metallography of Steel-Bonded Titanium Carbide: Martin Epner and Eric Gregory, Sintercast Corp. of America.

Combinations of titanium carbide and alloy steels containing up to 65 volume pct hard phase, made conventional powder metallurgical techniques involving liquid phase sintering are described.

Unlike most cermets, these composite materials are capable of being annealed and hardened in a manner similar to alloy steels. In the annealed condition they can be machined by conventional chip removal techniques. In the hardened condition their properties are similar to those of cemented tungsten carbide rather than to those of alloyed steel.

Some of the effects on properties and metallography of variations in the carbide concentration, alloying elements and heat treatment are discussed. One composition, i.e. 45 volume pct titanium carbide 55 volume pct chromium-molybdenum-steel is described in more detail.

Presentation Highlights of the Third Plansee Seminar in Reutte/Tyrol: Werner Leszynski, Schwarzkopf Development Corp.

2:00 to 5:00 pm, Lorenzo Carter

Symposium on Liquid Phase Sintering

(Sponsored by the Powder Metallurgy Committee)
Program will appear in October JOURNAL OF METALS.

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WHISKERS

by George A. Hoffman

Tiny perfect, crystal filaments, with strength approaching the theoretical limit of atomic cohesion, may be the building-blocks of the astronauts.

ACHIEVEMENT of the full strength available from atomic cohesion is the ultimate goal in the improvement of structural materials.

At present, most efforts to strengthen structural materials follow the metallurgical approach, such as alloying, to gain higher strengths in metals. But to this day the highest strengths developed by metallurgical means are still only a small fraction of the strengths theoretically obtainable from the flawless cohesion of atoms in a metal. On the other hand, fine filaments have attracted much attention lately because of the substantial improvement in strength that can be obtained by this technique. Indeed, fine crystal filaments—commonly called *whiskers*—have demonstrated the highest strengths known in materials, in some instances approaching the theoretical limit of atomic cohesion.[1]

Properties of whiskers, and the structural characteristics of hypothetical materials composed of them, permit a comparison of the weights of tension structures made from whiskers with the weights of structures made from conventional materials. Reductions to one-fifth of the conventional weight appear to be feasible, assuming that whiskers could be mass-produced into usable forms. This possibility should be of great interest in the design of astronautical

GEORGE A. HOFFMAN is Engineer, Aeronautics Dept., The Rand Corp., Santa Monica, Calif.

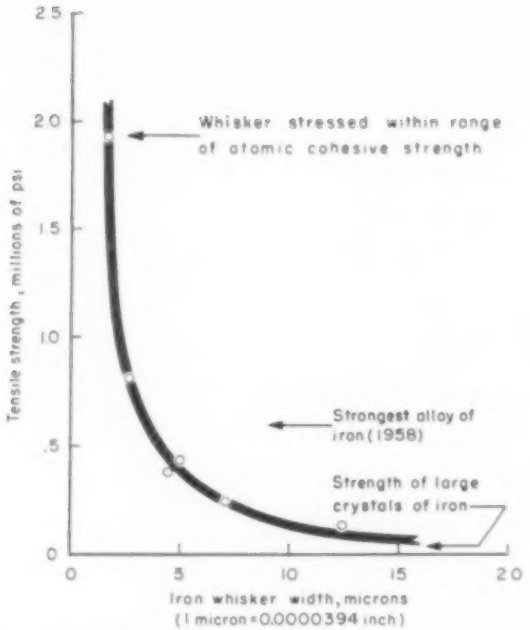
Tensile strength, millions of psi
Whisker stressed within range of atomic cohesive strength
Strongest alloy of iron (1958)
Strength of large crystals of iron
Iron whisker width, microns
(1 micron = 0.0000394 inch)

Fig. 1—The strength of pure iron whiskers as a function of their width.

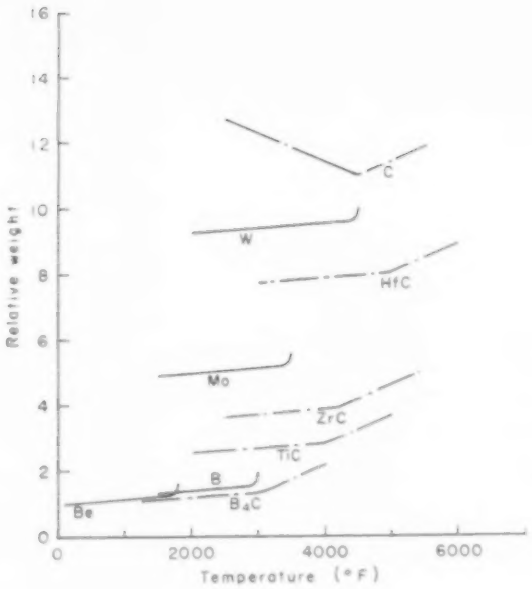

Fig. 3—The hypothetical relative weight of optimum whiskers.

vehicles, where weight reduction in the predominantly tension-designed structure can permit a considerable improvement in performance.

Strength of whiskers

Increasing strength with decreasing crystal dimensions was observed as early as the Nineteenth century. In the past decade this strengthening trend was observed to progress at a much steeper rate as crystal sizes were reduced beyond, say, 0.0001 in., Fig. 1. Only in the past three years have whisker strengths been finally tested at levels near the atomic cohesion strength. This strengthening effect has been demonstrated not only in iron, carbon, and many metals, but also in such compounds as oxides, halides, and carbides. It is also noticeable in thin films and platelets of many materials.

Several theories have been advanced to explain the great strength of whiskers.[1] Some explanations are based upon the low incidence of edge dislocations—a type of crystal fault—that can exist within the limited width of the whiskers, while others are based upon the restraining forces on crystal surfaces. In general, it is postulated that the strongest whiskers contain only screw dislocations along their axis and almost no edge dislocations—Figs. 2a and 2b. Furthermore, the growth mechanism of whisker tips has also been explained by the dislocation theory on the assumption of a spiraling growth around a single screw dislocation, Fig. 2c.

This fortuitous growth by orderly nucleation on the steps surrounding a screw dislocation almost eliminates the weakening edge dislocations in whiskers. Since the frequency of edge dislocations affects the tensile strength, a virtually perfect crystal lattice is formed, and the full strength of atomic cohesion is realized. Various theoretical calculations of this cohesion—or upper strength limit of *perfect* materials—give an ultimate tensile stress anywhere from one-tenth to one-fortieth of the modulus of elasticity. Table I, which lists the highest stresses tested in certain whiskers, shows that the actual ultimate stress is indeed of the order that theory predicts.

Other properties

Many other notable properties of whiskers have been observed or inferred from the assumed absence of edge dislocations:

- Metallic whiskers exhibit a plastic range, while most compounds can sustain only elastic strains up to failure.

- The modulus of elasticity of a whisker may differ radically from the modulus of large polycrystalline amounts of the same material, and can range from a halving to a doubling of the polycrystalline modulus. This effect results from the uniform orientation of the crystal axis in whiskers.

- Creep has not been observed in whiskers below the normal recrystallization temperature, implying considerable strength retention at elevated temperatures, even close to the melting point.

Whisker materials

Loading conditions of future astronautical vehicles will probably result in flight structures, designed predominantly by tension criteria. Tanks, cabins, instrument enclosures, and the like are examples of components that will be tension-loaded by pressurization. Since such structural components must be as

light as possible, exploitation of the superior tensile strength of whiskers might be a way to reduce their weight.

It is customary to use the density:ultimate-tensile-strength ratio in comparing the weights of tension structures made of various materials. The criterion for best design is the choice of materials that yield minimum values of this ratio. As we have seen, ultimate stress of the best whiskers is some fraction of their modulus of elasticity, this fraction probably being relatively constant for all materials. Then the density:strength ratio of whiskers is proportional to their density:modulus-of-elasticty ratio, which may consequently serve as an approximate criterion for choice among whisker materials.

In Table II, structural properties of certain materials are listed together with their density:modulus ratio. The most promising whisker materials for room-temperature use seem to be boron carbide and beryllium, which are competitive at ratios of 1.4 and 1.5 x 10^{-4} in.$^{-1}$, respectively.

Comparison of whisker materials at elevated temperatures is based upon the assumption that strength deteriorates slowly at first, but then rapidly between the recrystallization and the melting temperatures. Recrystallization temperature for metals and some carbides is roughly proportional to the melting temperature in degrees Kelvin or Rankine.

Therefore, it is sufficient to know only the density, modulus, and melting temperature and some simple assumption as to the modulus decrease with temperature, to derive theoretically the relative weight of equal-strength whiskers of various materials at various temperatures. If a beryllium whisker is designated to have a reference weight of unity, relative weights can be plotted for the least-weight metals and the least-weight carbides at elevated temperatures, as in Fig. 3. The particular materials plotted in Fig. 3 may be considered optimum within our present knowledge.

Structural materials made from whiskers

The structural properties of hypothetical bonded whisker materials can be calculated in advance by making a few assumptions:

- Beryllium whiskers will be the basic ingredient of the material; they can sustain 3 pct elastic strain.
- Properties are derived at 70°F; relative weights at higher temperatures can be obtained from the proportions indicated in Fig. 3.
- The modulus and the strength have been reduced by 20 pct as a penalty for the weight of non-load-carrying binder. This whisker binder or matrix is analogous to the plastic that binds glass fibers in plastic-impregnated-fibered glass: the fibers carry most of the tension load, while the plastic is very lightly stressed in shear.
- Biaxially stressed sheets are assumed to be composed of two bonded layers of mutually perpendicular fibers, each layer being active only in transmitting the tensile stresses parallel to the whiskers.

Shown in Table III are the results of these calculations, including the properties of beryllium, a structural material that has some great potentialities for space vehicles," and those of titanium, a structural material in present-day use. The properties

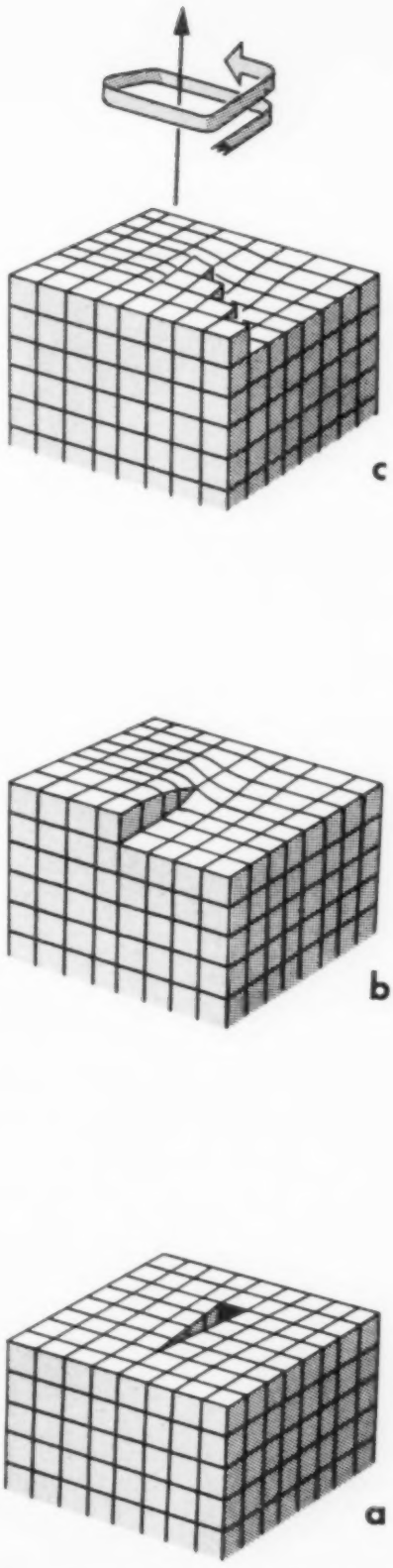

Fig. 2—Crystal lattice faults and growth: a) edge dislocation, b) screw dislocation, and c) spiral growth.

of whisker-composite materials shown in Table III may, at first, indicate the possibility of unusually high reduction in tension structural weight, but, on second thought, when certain deleterious effects are considered—as in the following section—a more realistic reduction factor will be derived.

Comparison with conventional structures

Sheets of conventional materials require doublers wherever the edges are fastened, and this doubler weight should be accounted for, even though it is only a small fraction of the total weight. The problem of fastening to an adjacent structure will be far more severe for whisker composite materials, with a proportionally larger weight penalty in most instances.

Extra weight of this kind was included in an over-all design comparison of such structural components as cables, biaxially stressed sheets fastened so as to be removable (as in some pressurized vessels), biaxially stressed and permanently fastened sheets (as in spherical vessels and some cylindrical tanks), and components in miscellaneous applications. The results, which are summarized in Table IV, show that, on the average, the weight of tension structures in space vehicles might be reduced to one fifth of their present weight if whisker composites were available.

Feasibility of mass-producing whiskers

If whiskers are to be exploited structurally, it should be first established that no insurmountable obstacles exist to their production in the needed quantities, qualities, and forms. Here must be considered the growing of whiskers in substantial quantities, as well as aligning, collecting, and finally binding them into usable shapes.

Several techniques to grow whiskers have been used in laboratories:[7]

Chemical reduction of metal halides: Reduction of metal chlorides, iodides, or bromides by means of the passage of hydrogen or the presence of a reducing agent (such as zinc) can result in the growth of filamentary crystals.

Electrolytic deposition: Silver, iron, and copper whiskers have been grown by electrolytic deposition from a molten salt of these metals.

Vapor deposition: A controlled supersaturation of the vapors of metals and their compounds usually can be made to precipitate whiskers of these materials.

High stress: When soft metals are under high stress, whiskers tend to grow from the bulk of the metal. The whiskers probably grow from their bases (not from their tips) in this situation. These were the first type historically observed to have high strength in metals such as tin, cadmium, lead, zinc, and others.

Table I. Tensile Stress of the Strongest Whiskers

Material	Modulus of Elasticity, Psi	Ultimate Tensile Stress, Psi	Stress / Modulus
Silicon[2]	23,000,000	550,000	1/42
Carbon[3]	1,000,000	88,000	1/11
Iron[3]	29,000,000	1,900,000	1/15
Silver[3]	11,000,000	240,000	1/46
Copper[3]	18,000,000	430,000	1/42
Quartz[3]	11,000,000	600,000	1/18
Zinc[3]	15,000,000	320,000	1/47
Cadmium[3]	10,000,000	130,000	1/77
Sapphire[3]	74,000,000	1,700,000	1/43

Drawn micron-size filaments: Considerable strength (though not of the order of whiskers) has been exhibited by hot-drawn metal filaments, and by fibers of compounds (such as glass) drawn from their liquid phase.

It may be assumed here that any of the growing techniques successfully demonstrated in the laboratory can be scaled up to pilot-plant production, and eventually to full-scale production, under sufficient economic incentives.

It is possible to envisage means for making the growth of whiskers orderly and thus improving their collectability. Alignment, thinness, and length could be controlled by the proper saturations, temperatures, and magnetic or electrostatic fields, and harvesting might be done by vibratory or mechanical scraping techniques.

Spinning and pressing

At this stage the whiskers would be in bundles or mats, held together by friction and electrostatic forces barely sufficient to prevent unraveling. Spinning of fine strands of whiskers from these agglomerates should be similar to the spinning of textiles or glass fibers, and these strands could then be woven into cables or sheets, whichever is desired.

This woven product, still weak in tension because of the lack of a good shear bond between adjacent fibers, could be brought into its final, strong form by at least two processes that can raise the cohesive bond between whiskers: impregnation with a binder, or pressing and heating.

Plastic-impregnated fibered glass is a good example of the first process of imparting good cohesion to filament aggregates. Currently plastics, such as phenolics, silicones, and polyesters, are in general use as cohesive binder materials, and a few laboratory experiments have been made with fibers in a

metal matrix. Plastic resins can be used at present only up to 600°F, but there are hopes that future developments—for example, boron polymer resins—will extend their usefulness to 1000° or 1200°F.

Other process for binding whiskers together is pressing and heating, a process analogous to powder and fiber metallurgy. This technique may prove successful with whiskers if the compacting pressures are low enough not to damage the strength of the whiskers, and if the temperatures are held below some critical value.

In sum, the production of structural elements, such as sheets and cables, which utilize the strength of whiskers, appears to be within the future state-of-the-art.

Potential value of whiskers

The usefulness of reducing the structural weight of space vehicles to one-fifth of conventional values can be visualized either in terms of the vehicle performance increase, or in terms of a comparison of the dollar *cost* of this technique with its dollar *value*.

For example, the four-fifths of structural weight saved in each vehicle stage could go into propellant, or into the payload of the last stage. A judicious apportionment of this weight could result in a significantly increased payload capacity, while leaving the take-off gross weight unchanged.

From the economic aspect it is important to establish that the utility of whisker composites will be larger than their eventual cost. One estimate of the future cost of whisker materials is $200 to $400 per installed lb, compared with a figure of $40 per installed lb for aluminum today. Since 1 lb of whisker composite can replace up to 5 lb of conventional materials, that pound is worth the (saved) cost of four pounds of structural weight. The value of saving a pound of structural weight has been variously reported to be between $100 and $1000 in aircraft, and to be even higher in missiles and astronautical vehicles; so that the utility of 1 lb of whisker material appears to be from $400 to $4000, as compared with its cost of $200 to $400.

Conclusions

It may be concluded that the exploitation of whiskers possesses attractive economic features, as well as significant possibilities for weight reduction and vehicle payload increases. The magnitude of possible improvement stems from the virtually perfect arrangement of most of the atoms in the crystals. This potential is so great that whisker exploitation should not be neglected, even though it may be 10 or 20 years into the future, and most of the problems have yet to be solved.

Topics for immediate research with whiskers are copious, since most of the considerations in this study are based on unanswered questions. When and if such questions are answered, whisker composites—approaching in strength the cohesion of atoms—would become a most valuable addition to the family of structural materials.

Table II. Selected Structural Properties of Materials with $\frac{\text{Density}}{\text{Modulus}} < 10$

Symbol	Density, Lb per Cu In.	Modulus of Elasticity, Millions of Psi at 70°F	Density / Modulus (— x 10^{-6}) In.	Melting Point, °F
Li	.019	2	9.5	370
Be	.066	44	1.50	2340
B	.083	50	1.66	4200
Al	.100	10.6	9.4	1200
Si	.084	23	3.6	2600
V	.217	24	9.0	3150
Cr	.260	45	5.8	3400
Fe	.283	29	9.8	2800
Mo	.369	52	7.10	4800
Tc	.415	59	7.0	4200
Ru	.450	63	7.1	3500
Rh	.450	55	8.2	3600
Os	.813	83	9.8	5000
Be_2C	.088	45	1.95	3800
BeO	.103	55	1.87	4580
B_4C	.091	65	1.40	4500
α-Al_2O_3	.137	52-74	2.6	3660
SiC	.115	70	1.6	4350
SiO_2	.083	11	7.5	3150
TiC	.178	51	3.5	5700
VC	.210	39	5.4	5130
ZrC	.242	49	4.9	6400
ZrO_2	.193	36	5.4	4700
$ZrSiO_4$	.154	24	6.4	4600
Mo_2C	.320	33	9.7	4870
WC	.567	102.5	5.5	5030

Table III. Hypothetical Properties of Whisker Materials and Others

Material	Density, Lb per Cu In.	Ultimate Tensile Stress, Psi	Modulus of Elasticity, Psi
Whisker composite in uniaxial tension	0.07	1,000,000	35,000,000
Whisker composite in biaxial tension	0.07	500,000	26,000,000
Potential structural metal: beryllium	0.067	50,000 to 100,000	44,000,000
Conventional metal: titanium	0.163	180,000	16,500,000

Table IV. Weight Reductions Possible with Whisker Composites in Tension Structures

Component or Application	Structural Weight—Conventional / Structural Weight—Whisker
Cables and rods	10 to 23
Removable plates and sheets	1.6 to 3.6
Pressure vessels, tanks, fuselage	Up to 8.5
Miscellaneous:	
Porous sheet transpiration cooling	10
Prestressing cables for ceramics, carbon	8
Rocket motor cases, exhaust cones	5
Tubing, ducts, cabin walls	8
Centrifugally tensioned components	4

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HOT-BLAST CUPOLA FINDS PLACE IN STEELWORKS

A Staff-Written Summary of Articles Appearing in "Stahl und Eisen", "Giesserei" and "Industriekurier Wochenausgabe Technik and Forschung", and a series of on-the-spot interviews by Journal of Metals' Managing Editor in Germany.

Cupolas, traditionally standard equipment only in iron foundries, have now found a place in melting scrap for steelmaking furnaces, thanks to the development of the continuous hot-blast cupola during recent years in Germany.

FOR well over a hundred years the standard melting furnace for iron foundries has been the shaft furnace called the cupola. A cold air blast has always been used, but as early as 1827, in Germany, a furnace was designed for the use of a hot air blast. But it was never built, because of the time required to bring air heaters up to temperature for the short runs traditional in iron foundries.

Almost one-hundred years later, experiments were undertaken at the Casting Institute of the Technische Hochschule in Aachen, Germany, with a view toward developing a hot-blast cupola which would raise smelting temperatures and improve the quality of castings.[1] The result of this was the installation of what was probably the first commercially operated hot-blast cupola at the plant of Georg Fischer AG in Schaffhausen, Switzerland in 1941. It had a coke-fired blast stove, and with the difficult coke supplies faced by the Swiss during World War II, this furnace's low coke requirements were a great help in maintaining production of malleable cast iron. Advantages gained from the unit included: lower coke requirements and hence smaller quantities of sulfur introduced into the metal, faster burning of the coke and therefore higher slag and iron temperatures, and possibility of substituting scrap for pig iron.

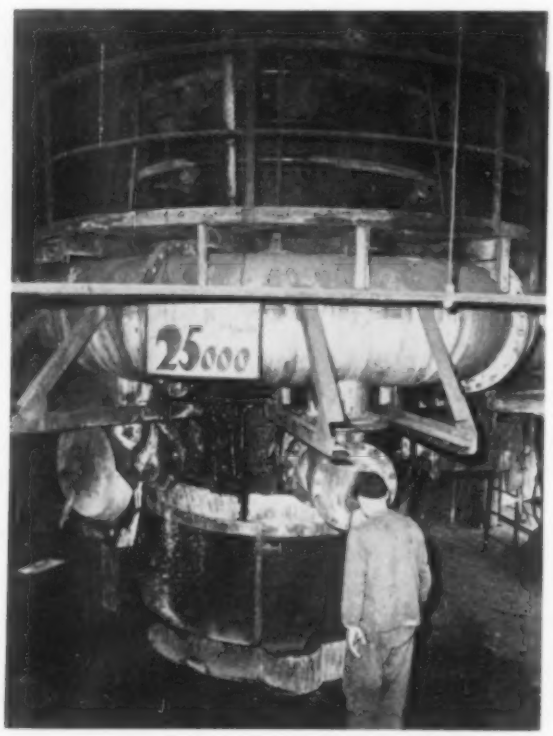

Fig. 1—The hot-blast cupola at the Hahnsche Werke AG in Duisburg-Grossenbaum, Germany.

Post-war developments of the hot-blast cupola were concentrated on designing a wind heater which could make use of the furnace gas for heat transfer and for burning. Two main problems had to be overcome: the low heating value of the furnace gas, and its high dust content. Increased furnace height and higher operating temperatures increased the CO content of the gas and solved the first problem. Wet dust removal techniques would lower the temperature of the furnace gas, and therefore an insulated cyclone was employed to solve the dust problem. Several types of recuperators were developed, but the German Schack-type tube recuperator, which permits easy dust removal, has probably been one of the more successful.

Useful in steelmaking

While originally designed for the iron foundry, the continuous hot-blast cupola was immediately siezed upon as a means of supplying open hearth furnaces with low-cost hot metal. The melt-down period in open hearths is time-consuming and costly. The purpose of the parallel operation of the hot-blast cupola is, therefore, to reduce this factor, thereby increasing the efficiency of steelmaking furnaces. Furthermore, the overall costs of melting scrap in a steel mill would appear to be lower in a hot-blast cupola than in the open-hearth furnace. And most important, in many cold-charged open hearth shops, the erection of a high-cost modern blast furnace is out of the question, and the hot-

blast cupola provides the only practical means of supplying hot metal.

It is possible for the basically operated hot-blast cupola to produce hot metal with a very high temperature—1500° to 1600°C. This is the result of the high rate of coke combustion in the cupola with the blast preheated to 600°C. The metal is low in sulfur because of the high temperatures in the cupola as well as the basic slag practice. The hot metal is, in addition, low in manganese and silicon, which permits rapid oxidation of carbon in the open hearth bath. The result is that the open-hearth charge can be made up of up to 55 pct cupola metal.

In a non-integrated German steel plant

The Hahnsche Werke AG in Duisburg-Grossenbaum, Germany, has three oil-fired open-hearths which have crane facilities for changing hot metal. Two of these furnaces are of 90 metric ton capacity and one of 80 tons.

Until recently they were charged with scrap and cold pig iron. But the output of the steel works was insufficient for the rolling mills, and it was decided to add to the plant's steelmaking capacity. Two avenues appeared to be open: the addition of an open-hearth furnace or an increase in the output of existing furnaces by utilizing a charge of hot metal. The second alternative was shown to be lower in cost, and the Gesellschaft für Hüttenwerksanlagen of Dusseldorf was called in to design a hot-blast cupola capable of supplying the steelmaking furnaces with up to 40 pct hot metal in their charge.[2]

A hot-blast cupola of 13 metric tons per hr capacity was thus constructed. Maximum blowing capacity of the furnace engine is 24,000 normal cu m of wind per hr under a maximum pressure of 1700 mm water gage. The unit includes two tube-type recuperators capable of heating air up to 600°C.[3]

The heavy steel plates of the furnace exterior are lined with refractories only in the smelting zone, but the entire exterior is cooled with water sprays. Before the furnace was put into operation, the 2 m above the tuyeres were lined with rammed magnesite upon which a slag coating has been built up. Areas subject to slag attack are lined with carbon blocks or rammed carbon, while points in contact with liquid metal are lined either with chrome-magnesite brick, rammed magnesite, or tar-dolomite brick.

For the cupola charge, the emphasis is on plant scrap and other scrap of known quality, since dealers bundles frequently contain sufficient nonmetallic material to cause a wide variation in slag composition. The charge also includes some 20 pct coke, 5 pct limestone, and 2 pct fluorspar.

The iron produced by this cupola has approximately the following analysis: 3.9 pct C, 0.10 pct Si, 0.35 pct Mn, 0.07 pct P, and 0.05 pct S. A partial slag analysis is as follows: 50 to 55 pct CaO, 20 to 25 pct SiO_2, 10 to 12 pct Al_2O_3, and 1 to 2 pct FeO.[3]

A second non-integrated plant

A subsidiary of *Felten & Guilleaume Carlswerk Eisen u Stahl* in Germany was producing steel from cold charge in two 35-ton open hearth furnaces. But steel capacity was insufficient to meet the requirements of the firm's wire rod mills, and it was decided to increase steel capacity from 80,000 metric tons to 110,000 tons. On the basis of the Hahnsche experience described above, a hot-blast cupola was installed by Gesellschaft für Hüttenwerksanlagen

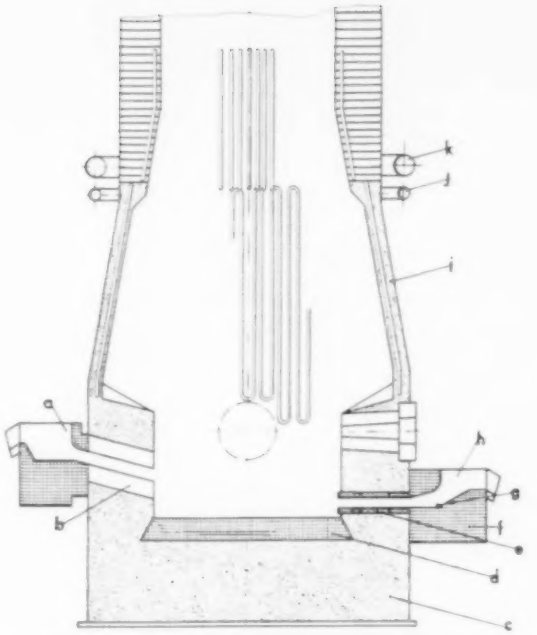

Fig. 2—Cross-section of hot-blast cupola at Salzgitter, Germany, showing the most recently installed cooling system: a) slag syphon, b) carbon block, c) rammed carbon, d) magnesite, e) magnesite brick, f) magnesite, g) residual iron syphon, h) iron syphon, i) fire clay, j) water supply, k) steam discharge. From "Metallurgy of Liningless Cupola Furnaces" by E. L. W. Lobbecke.

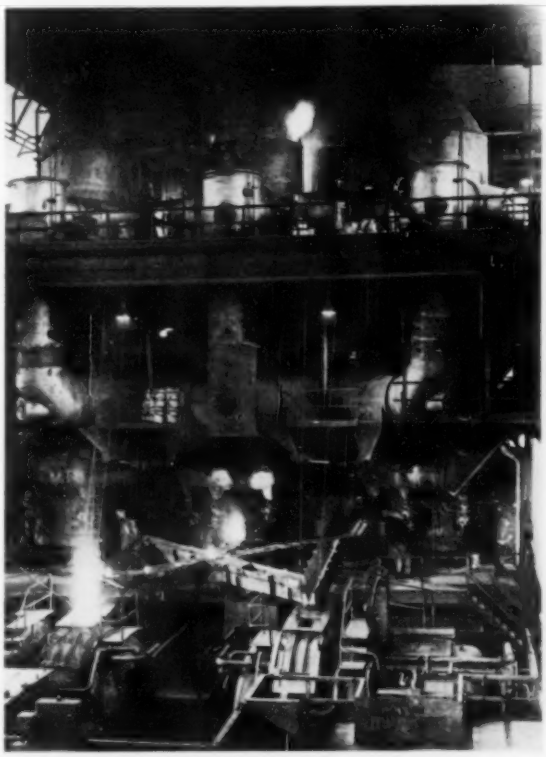

Fig. 3—Three hot-blast cupolas are in operation at the integrated steel works of Huttenwerk Salzgitter AG in Germany.

to meet this requirement without the necessity of adding another open hearth.[4]

The installed cupola has a capacity of 8.5 to 9.5 metric tons per hr from a charge made up of 17 to 18 pct coke, 5 to 8 pct lime, and 1 to 2.5 pct fluorspar.

Open hearth output was shown to be a maximum with a charge made up of 50 to 60 pct cupola iron. When using the same weight of charge, this resulted in increasing furnace capacity by as much as 35 pct, but it was also possible to use larger charges in the open hearth, so that the overall furnace capacity could be increased by as much as 50 pct.

For other steelmaking furnaces

Not only has the hot-blast cupola been found useful for melting scrap to provide the open hearth with hot metal, but it has now been installed to supply hot metal to an LD converter at the plant of Gussstahlwerk Witten AG in Germany. This is the subject of an article appearing on page 599 of this issue of JOURNAL OF METALS. A second plant making use of the hot-blast cupola-LD converter combination is to be erected in the U. S. by Acme Steel Co.

For an integrated steel plant

Thus far we have spoken only of non-integrated steel plants where the steelmaking furnaces were previously operated on a cold charge basis, but there is at least one case in which the hot-blast cupola has been installed in an integrated steel works—the Hüttenwerk Salzgitter AG in Germany.

This recently reconstructed plant has three blast furnaces operating on local low-grade ores, supplying hot metal to three 50-ton basic converters. The plant also has three 150-ton open-hearth furnaces which are charged with scrap and 20 pct duplex hot metal from the converters. The open hearths had a capacity of some 32,000 metric tons per month, while rolling mill requirements for open-hearth steel—largely for the plate mill—were as much as 50,000 tons.[5]

This increased output could be met by the erection of a hot-blast cupola plant and changing over the open-hearth charging program to 20 pct scrap and ore, 40 pct blown metal, and 40 pct cupola iron. It was determined that such an installation would be more than $6 million cheaper than the installation of further blast furnaces and open hearths.

The resulting hot-blast cupola installation comprised three furnaces and was capable of supplying between 600 to 1200 metric tons of hot metal per day. It was designed by Strico GmbH of Gummersbach, Germany, in collaboration with Salzgitter Industrie Bau GmbH and the Hüttenwerk Salzgitter AG. Two hot-blast cupolas are in constant operation, each with a hot-blast recuperator, while the third furnace is held in reserve. These furnaces operate on a 14-day campaign. The hot blast is supplied by two turbo compressors rated at 30,000 normal cu m per hr under a pressure of 4000 mm water gage.

The main difference in design between these cupolas and previous furnaces was the installation of boiler tubes around the upper portion of the furnace in order to recover lost heat in the form of steam. Initially this boiler proved unsuccessful, but a second design has proven to be satisfactory; this is in the form of a closed-top cone which reaches to the gas off-take pipes. The operating pressure of this new cooling system is 42 kg per sq cm. Saturated steam at about 250°C, taken from the system, is super-heated to 420°C by the flue gases of the cupola.

With a slag volume of 5 to 6 pct of the metallic charge, the slag had the following composition: 52 pct CaO, 26 pct SiO_2, 12 pct Al_2O_3, and less than 1 pct FeO. The cupola iron was as follows: 2.8 to 3.2 pct C, less than 0.1 pct Si, 0.3 to 0.5 pct Mn, 0.08 to 0.1 pct P, and 0.06 to 0.09 pct S. With a cupola iron of this analysis at a temperature of 1400° to 1430°C a charge of 55 pct produced a maximum open-hearth efficiency by shortening melting and oxidation. With a charge of 40 pct cupola iron, 40 pct blown metal, and 20 pct scrap ore, output was about 27 tons per hr.[5]

Experiments have been undertaken on different slag compositions, primarily with a view toward using a less basic slag in the furnace. A slag of 48 pct CaO, 11 pct MgO, 42 pct SiO_2, 11 pct Al_2O_3, and 1 pct FeO has been most successful. Future operations will be carried out with this highly fluid slag because of its less harmful action on refractories, better desulfurization, and better adaptability for cement production.

Operations of the hot-blast cupola plant at Salzgitter have shown that through savings on charging materials and increased open-hearth output—amounting to about 39 pct—that the utilization of cupola iron is economically feasible in an integrated steel plant. Capital costs were lower than other alternatives, and there was a time saving of one year when compared with the erection of an additional blast furnace.

Conclusions

The cupola—originally the exclusive tool of the iron foundry—has, thanks to the development of hot blast techniques, become a vital factor in providing cold-melting open hearth steel shops with hot metal. Moreover, it has more recently found a place in supplying LD converters with metal, and finally it has even been installed in a fully integrated steel works so as to increase steel capacity without the addition of a costly blast furnace.

We have mentioned only the German story, but there are now at least 24 hot-blast cupola plants throughout the world, including such countries as India and Egypt, where they represent a considerable capital saving.

One additional factor should be mentioned. In addition to melting scrap, the hot-blast cupola can smelt other materials. At the Hahnsche plant, the hot-blast cupola has been shown to be capable of smelting up to 10 pct iron ore, although greater quantities result in increased coke requirements and excessive iron-oxide content of the slag and thus reduced desulfurization. Tests with Krupp-Renn pellets have been quite successful and have shown that greater quantities can be charged. Further details are given in the following article on the hot-blast cupola LD converter plant at Witten, Germany.

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HOT-BLAST CUPOLA -- LD CONVERTER STEELMAKING

Summarized from an article in the 6th March 1958 issue of
STAHL UND EISEN
by Adolph Richter, George Cohnen, and Paul Jacobi
Together with on-the-spot-staff-written notes

In order to increase output of alloy steels at the Gussstahlwerk Witten in Germany a basic hot-blast cupola was installed whereby scrap is melted into liquid iron which is charged either into an open hearth or into an LD converter, used largely for duplexing with electric-arc furnaces. The 23-metric-ton-per-hr cupola has proven successful in combination with these units in producing high-quality steels.

GUSSSTAHLWERK Witten is a non-integrated plant for the production of high-grade and alloy steels. Steelmaking furnaces include four open-hearth furnaces of 60 metric tons capacity each and one of 80 tons capacity, together with four electric-arc furnaces of capacities ranging from 7.5 to 15 tons.

Plans for linking the open-hearth and the electric-furnace steel plants, situated some distance apart, were examined with a view toward making duplexing a possibility and increasing steel output. In this connection, the idea of interpolating between the two melting plants a premelting furnace for the production of liquid metal and a plant using the LD converter process took form.

After careful studies in cooperation with the Geselleschaft fur Hüttenwerksanlagen mbH in Düsseldorf, Germany, and by profiting from the experience gained from the basic hot-blast cupolas at two other German works,[1] Witten decided in favor of a melting unit of a similar type.

The LD vessel, which was also to be installed, was to perform two tasks: first, to increase the electric-furnace steel capacity by duplexing in the electric-arc furnace, thus improving the quality of the special steel produced and reducing the specific consumption of electric current and electrodes. The second task consisted of producing quality steels by direct pouring, thereby eliminating the cost of processing in electric-arc furnaces.

In order to achieve the most effective economical working, a hot-blast cupola of a maximum of 23 metric tons per hr or 10,000 tons per month capacity was installed. Its water-cooled shaft has no refractory lining. The tuyeres have water-cooled single-piece copper nozzles, as in blast furnace practice, which makes it possible to operate 24 hr per day at an equal hourly rate.

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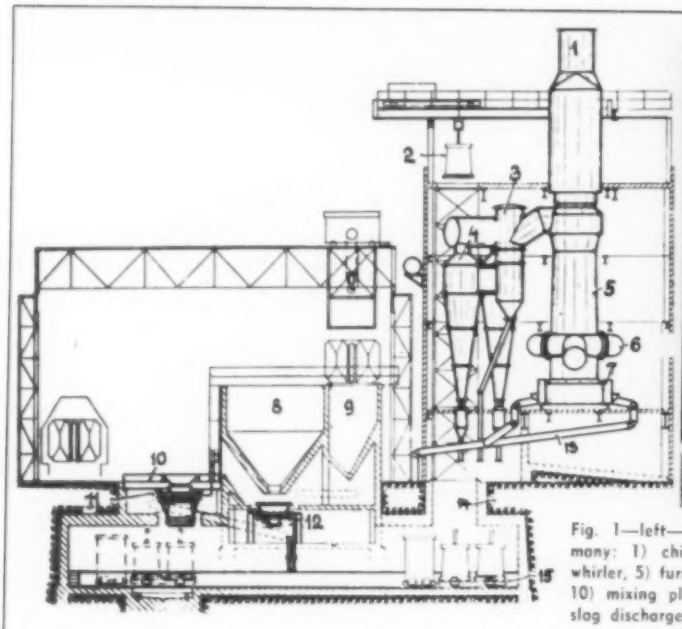
The iron drips through a highly basic slag formed of limestone, fluorspar, and dolomite and is thereby cleaned and desulfurized. The slag leaves the furnace continuously through the same tap-hole as the iron and passes into a siphon where it is separated.

Cupola iron has approximately the following analysis: 3.4 to 4.2 pct C, 0.4 to 0.9 pct Mn, 0.08 to 0.17 pct P, 0.05 to 0.3 pct Si, and 0.01 to 0.07 pct S. In addition to scrap, the cupola charge includes about 21 pct coke, 5 pct limestone, and 1.5 pct fluorspar.

Although open-hearth practice requires iron with about 3.5 pct C and 0.04 pct S, the LD converter requires over 4 pct C and relatively low sulfur. The carbon content depends chiefly on the percentage of coke in the mix and the temperature of the iron. Owing to the endothermic carburizing process, it increases as the temperature rises, and tapping temperatures are maintained in the range of 1510° to 1520°C. Consistent with the demand for a carbon content, the sulfur can be kept on the average of 0.050 pct, so that desulfurization in the ladle is unnecessary. The phosphorus content is entirely dependent on the phosphorus content of the charge, since dephosphorization worth mentioning does not take place in the cupola.

Smelting capacity of the cupola is essentially a function of the charge and the volume of blast. It was found that the influence of the blast is considerably greater, so that an increase in the efficiency can be obtained more effectively and quickly by adapting the blast. Insignificant variations of the blast temperature are not conducive to this end.

Carbon dioxide formed in the smelting zone of the hot-blast cupola is largely reduced to carbon monoxide. The smelting zone is reduced to a minimum, and as a result, the temperature of the gases drop considerably immediately above the smelting zone. With the height of the furnace fixed at 10.5 m, an



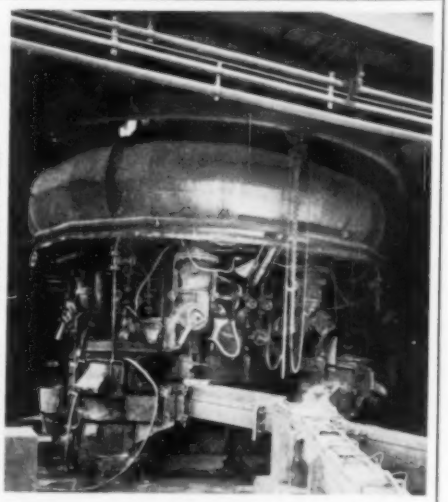


Fig. 1—left—Cross-section of hot-blast cupola at Witten, Germany: 1) chimney, 2) charging bucket, 3) dust collector, 4) whirler, 5) furnace, 6) bustle ring, 7) siphon, 8) coke, 9) fluorspar, 10) mixing platform, 11) scrap weighing, 12) flux weighing, 13) slag discharge, 14) elevator shaft, and 15) bucket car.

Fig. 2—above—tapping side of the cupola.

extensive heat exchange takes place between the combustion gases and the burden. The resulting top gas temperatures are low—120° to 200°C.

The gas cleaning plant at Witten is different from that of previously constructed hot-blast cupola plants, in that for the first time wet dust-removal techniques are used instead of only dry precipitators. Two whirler-type dust catchers have been installed to take care of the preliminary removal of dust. The gas then passes into either of two Theissen washers of 20,000 normal cu m per hr capacity for reducing the dust content of gases to 0.05 g per normal cu m.

Included in the cupola plant is an engine room with three rotary compressors of 15,000 normal cu m per hr capacity at a pressure of 1700 mm of water. Adjoining these are two Schack tubular recuperators of 15,000 normal cu m per hr capacity each, used for preheating the blast to 600°C. Passing from the Theissen washers through dehydrating towers, some 40 pct of the furnace gas is used to preheat the blast in these recuperators, and the remainder is fed into the boiler house.

The cupola: A cross-section of the hot-blast cupola, as well as the storage bins with their discharge and transport installations, is shown in Fig. 1. Weighing is automatic throughout, and owing to the automation of the charging gear and the cupola furnace control, only seven men per shift are required to operate the plant.

The tapping side of the cupola with the runners and the hot-blast bustle pipe with the underlying blast nozzles is shown in Fig. 2. To the left and right are the two slag skimmers, which are operated alternately.

Capacity and output: The cupola plant has been designed for operation at three different rates: 12, 18, and 23 metric tons per hr. As may be seen from the illustrations, two units each are available for blast pre-heating and gas washing, so that only one of them need be operated when running the furnace at low output. On the other hand, peak furnace output calls for the operation of both recuperators, two compressors, and both gas washers. The cupola plant has now been in operation for almost two years, during which time it has produced a monthly avg of 9000 metric tons of iron at an avg rate of 15 tph.

Costs: The cost for constructing the hot-blast cupola at Witten, Germany, has been a little over $1 million, as compared with the estimated cost of about $5 million for a blast furnace of similar output. The construction time is shorter for the cupola, and furthermore, it does not require as large an area as does a blast furnace, a factor which is of some importance in crowded plants such as Witten.

As to operating costs, the cost of melting scrap in a cupola is obviously considerably below that of smelting ore in a blast furnace, but such costs are dependent on the price of scrap. On the other hand, it is possible to use low-quality scrap, such as blast furnace bundles and rusty country scrap. These qualities can not be used either in the open hearth or in the electric furnace. In times of high scrap prices, recourse can be made to prereduced iron, for example Krupp Renn pellets.

Smelting ore and pellets

A series of 10 hr tests were run in the hot-blast cupola with increasing percentages of Krupp-Renn pellets. The furnace pressure, which normally is 380 to 400 mm water column, was expected to rise because of the greater compactness of the charge, but it remained the same. When using 25 pct pellets, the addition of coke was increased 2 pct above normal, but the melting of a part of the pellets in the hearth sump caused a drop in the temperature of the runner iron to 1460° to 1480°C from 1510° to 1520°C. With 50 pct Krupp-Renn pellets in the charge, output decreased. Table I shows the cupola and coke consumption at a blast of 9000 to 12,000 normal cu m per hr.

Tests in the cupola were also made with Brazilian ore, Kantorp sinter, and Kiruna C 1 ore. The Bra-

zilian ore was in lumps of 50 to 120 mm diam. The portion of ore or sinter was raised from 10 to 15 and finally to 20 pct. To provide the carbon required for reduction, heating, and carburizing, the quantity of coke was tentatively increased to 32 pct.

In the case of the 10 pct ore test, the total coke portion could be reduced to 27.5 pct. As shown in Fig. 3, the original smelting capacity of 16.5 tons per hr dropped considerably after the addition of 10 pct ore. But by increasing the volume and pressure of the blast it was possible to obtain a smelting capacity of 14.5 tons per hr, composition and temperature of the iron remaining normal.

Increasing the quantity of ore to 15 pct resulted in a further loss in capacity. Due to the higher blast pressure, the first blow-outs on the siphon occurred, making it necessary to decrease the blast volume. When raising the proportion of the ore in the burden to 18 to 20 pct, difficulties increased. This percentage was the limit. A further increase of the proportion of ore was not feasible. Enriching the blast with 25 pct O_2 was likewise no improvement.

Siegfried Tunder of the Gesellschaft fur Hüttenwerksanlagen mbH in Düsseldorf reports that tests which have been conducted with a basically operated hot-blast cupola in Sweden have shown that large quantities of sponge iron, irrespective of what percentage of gangue, can be successfully smelted. It is unnecessary to obtain a 100 pct reduction of the ore, sponge iron containing 15 pct iron oxides being generally satisfactory. This fact is of importance insofar as it is comparatively easy to reduce iron by about 85 pct, whereas the reduction of the remaining 15 pct is a time-consuming and costly matter. Tunder predicts the construction of a steel works incorporating a sponge iron plant, a basic hot-blast cupola, and an LD converter, Kaldo, or rotary furnace, for the production of steel at a low cost.

Open-hearth efficiency improved

The output for the first year of production of the hot-blast cupola was entirely transferred to the open-hearth steel plant, because the LD converter had not been completed. The open hearths were, thus, able to operate on approximately 40 pct hot metal, resulting in higher output and decreased heat consumption.

For open-hearth operation during the first seven months of 1956, when liquid charging was not yet practiced, heat consumption per metric ton of crude steel was 1.63×10^6 kcal, while for the second half of 1956, when furnaces were charged with an average of 41 pct cupola hot metal, the figure was 1.28×10^6 kcal, a reduction of 21.5 pct. Output in tons per hour for the same period increased by 20.8 pct. The increase in efficiency is reflected by a decrease in melting time and a 30 to 35 pct increase in tap weight, together with a corresponding improvement in hearth-area loading.

Fig. 4 shows the output of the open-hearth furnaces when charging with varying proportions of cupola hot metal. An optimum range is clearly recognizable, lying at 50 pct for the large furnaces, and 45 pct for the smaller ones.

In the sequence of open-hearth charging, the time when the hot metal addition is made is of considerable importance. To obtain the optimum effect it proved advantageous at Witten to add the first ladle after charging half of the scrap and to follow up with the second ladle immediately after completing the scrap charge. If added later, the liquid

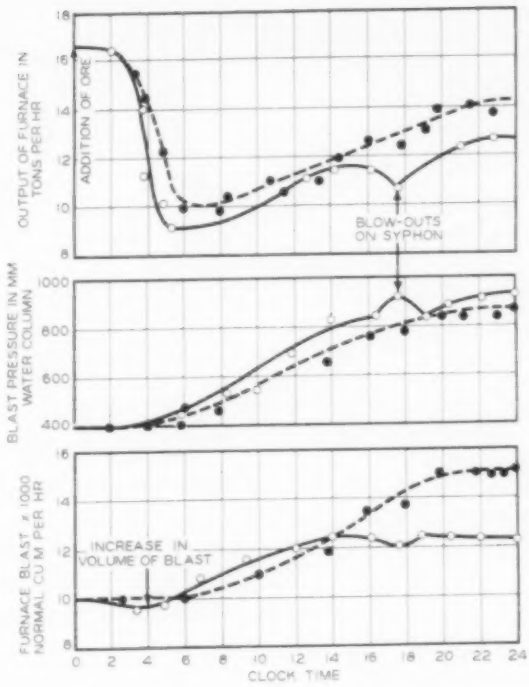

OUTPUT OF FURNACE IN TONS PER HR
ADDITION OF ORE
BLOW-OUTS ON SYPHON
BLAST PRESSURE IN MM WATER COLUMN
FURNACE BLAST, 1000 NORMAL CU M PER HR
INCREASE IN VOLUME OF BLAST
CLOCK TIME

Fig. 3—Dependence of cupola efficiency on volume and pressure of blast with ore in charge. Solid line: 20 pct iron, 62 pct scrap, 15 pct Kiruna ore of 65 pct Fe, 28 pct coke per mix, and 2 pct regulation coke. Broken line: 20 pct iron, 70 pct scrap, 10 pct Kiruna ore, 26 pct coke per mix, and 1.5 pct regulation coke.

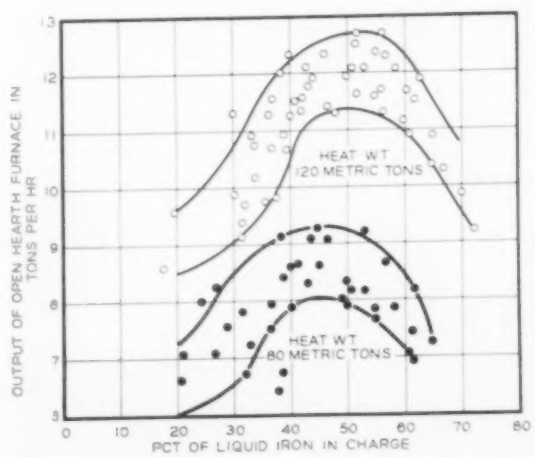


Fig. 4—Output of open hearth in relation to percentage of liquid iron in charge.

Table I. Hot-Blast Cupola Operation When Charging Krupp-Renn Pellets

Proportion Pellets Charged, Pct	Cupola Output, Metric Tons Per Hr	Pct	Coke Consumption, Pct of Charge
0	15	100	18
25	14.7	98	20
50	12.5	84	21

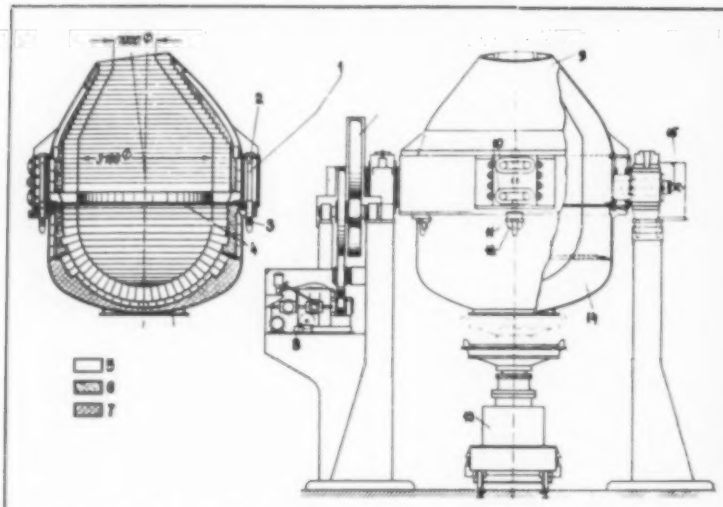


Fig. 5—LD vessel: 1), 2), and 3) bolts and cotters, 4) joint, 5) magnesite, 6) dolomitic magnesite, 7) fire clay, 8) tilting gear, 9) upper part, 10) tightening locks, 11) tightening cotter, 12) base cotter, 13) movable lift truck, 14) bottom part, and 15) water cooling.

Fig. 6—The two parts of the LD vessel at Witten are fastened by means of bolts and cotters.

iron does not become fully effective. In addition, difficulties will be experienced in pouring the liquid iron into the furnace, due to violent frothing.

The LD converter

As mentioned earlier, the second task allotted to the hot-blast cupola was to supply liquid iron for an LD converter, which in turn was intended to make possible duplexing in the electric-arc furnaces as well as direct pouring from the LD vessel.

The LD plant started operation in April 1957, but it was not without trouble in the beginning, and even today deficiencies are observed and have to be remedied. However, it can already be claimed that the LD process is proving its usefulness in fulfilling the tasks set for it.

Oxygen supply: Full utilization of the plant is dependent on the availability of oxygen. It was reckoned that approximately 50 normal cu m of oxygen would be required for refining one metric ton of steel, and a further 5 to 8 for heating up, making a total of about 58 normal cu m. This figure has now been reduced to the level of about 52 normal cu m.

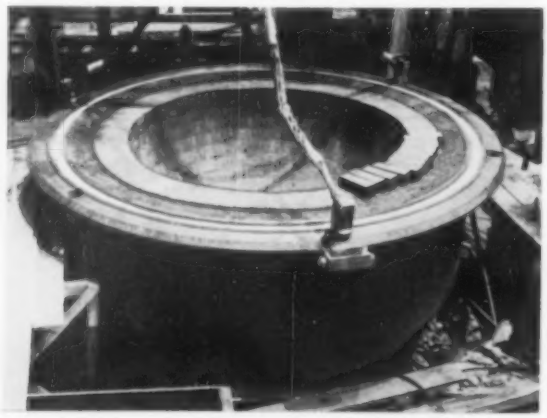


Fig. 7—Completely lined lower part of LD vessel.

Gussstahlwerk Witten did not possess oxygen producing facilities, but in discussions with Linde Corp. of Munich, a solution was found insofar as Linde erected in the works area a classical production plant of 1500 normal cu m per hr capacity of 99 pct O_2. For the present, the LD plant is run on two shifts, since the oxygen supply is sufficient for not more than 15 heats per day.

The LD vessel: In planning the one-converter LD plant at Witten, the design of the vessel itself was given particular attention. . . It has two unique features: first it consists of two parts, and second the lower one has a lining shaped in the form of a hemisphere. The two-part design is intended to make relining as short an operation as possible for the one-vessel plant. A completely bricked bottom part is kept in readiness at all times in order to cut relining to less than 40 hr. Furthermore, the bipartite design of the vessel speeds up cooling, since the two parts, when separated, cool more quickly than a one-part vessel. A sectional view of the vessel—built by Bamag in Germany—as well as a schematic representation of the entire unit, is shown in Fig. 5.

The mantle ring, which connects the two parts of the vessel, is bipartite and is kept together by tension locks. The supporting trunions are welded to the sides of the vessels and fitted with water-cooled bushings. For fastening the lower and upper parts, six bolts with base and tightening cotters are distributed around the circumference. The vessel is supported by two welded pillars. The tilting gear is located underneath the platform. The lift truck, placed below the vessel, has a lifting power of 100 metric tons and a height of lift of 700 mm. It is capable of lifting and transporting the completely lined lower part of the vessel.

The completely lined lower part of the vessel—Fig. 7—is put on a lift truck and moved under the upper part of the vessel, where it is hydraulically raised and fastened by means of bolts and cotters —Fig. 6.

Attention is drawn to the fact that with a 700-mm thick lining and a melt of 20 metric tons, the parting

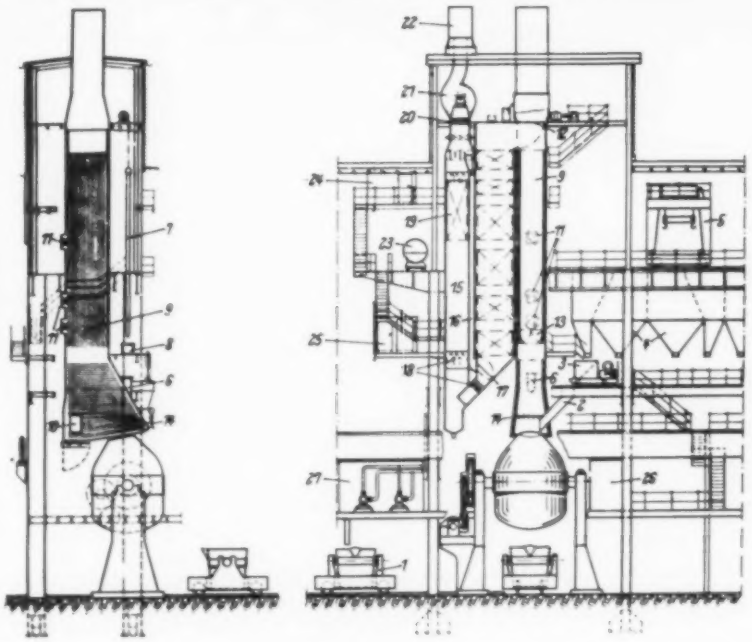


Fig. 8—LD vessel with waste gas cooling and cleaning plant: 1) transport truck with pouring ladle, 2) chute for fluxes, 3) flux weighing machine, 4) flux bin, 5) crane for flux bucket, 6) nozzle opening, 7) nozzle, 8) nozzle holder, 9) draft flue, 10) entrance hatch in hood, 11) oil burner, 12) boiler reversing flaps, 13) double flaps, 14) secondary blast nozzles, 15) filter flue, 16) empty shaft, 17) reversing flaps, 18) washer, 19) electrical filter, 20) control flaps, 21) exhaust fan, 22) hood, 23) boiler drum, 24) oxygen valve control, 25) boiler control, 26) LD vessel control, and 27) circulating pumps.

line between the unsymmetric upper part and the symmetric lower part is above the surface of the bath. This arrangement is intended to prevent break-throughs by keeping down erosion.

The lining of the vessel consists of a 120 to 150 mm thick insulating fire-clay layer in the bottom part and a 125 to 250 mm thick permanent lining of magnesite brick in the upper part. The working lining is made of sintered dolomite brick of 375 mm thickness in the bottom part and 450 mm in the upper part of the vessel. The interstices between the working lining and the permanent lining, unavoidable on account of the brick sizes used, are filled up with a mixture of tar and dolomite. When this backing or the permanent lining appears, the campaign of the vessel is considered completed. Since using dolomite, the lining has been lasting some 250 heats, and the consumption of dolomite is maintained at 10 kg per metric ton. The heats vary between 20 and 35 metric tons, depending on whether the LD steel is used for half or full duplexing in the electric-arc furnace or for direct pouring.

The oxygen lance: Oxygen is supplied by a water-cooled 10 m nozzle, which is provided with a copper mouth piece. The nozzles used so far have been of three different diameters: 28, 30, and 32 mm.

By means of a winch geared from the control station and adjustable to different speeds, the nozzle can be raised or lowered. At all times two nozzles are connected to the oxygen and water supplies so that in an emergency one is immediately available. For safety reasons the movement of the nozzle is blocked when the nozzle holder is not open, when the vessel is inclined at more than 5°, or when the cooling water flow is out of order. The spherical shape of the vessel makes it absolutely necessary that the oxygen be blown onto the bath concentrically from a fixed nozzle. The volume of oxygen and the blowing pressure are also of importance. Blowing requires 20 to 30 min, depending on the weight of the charge.

Blowing cupola iron

The iron furnished by the cupola furnace is low in silicon and manganese. Its composition is as follows: 3.4 to 4.2 pct C, 0.05 to 0.30 pct Si, 0.40 to 0.90 pct Mn, 0.08 to 0.17 pct P, 0.07 pct S maximum, and 0.009 to 0.013 pct N_2.

Although the use of nearly commercially pure oxygen affords a wide latitude in respect of the iron to be blown, a carbon content exceeding 3.8 pct was found desirable for obtaining sufficiently high percentages of carbon and manganese, as well as satisfactory steel temperatures. This is particularly true of steels requiring greater additions of alloys.

The thermal efficiency of cupola iron being low, it is required to possess high physical heat. For this reason desulfurization by means of soda, resulting in thermal losses, is as far as possible avoided, and the attempt is made to control the sulfur at percentages below 0.05. Since all grades of steel are uniformly blown down to a soft final analysis, it does not present any difficulties in keeping the sulfur content below 0.025 pct. The same is true of phosphorus.

The temperature of the iron at the time of pouring into the LD vessel ranges from 1300° to 1400°C, the highest frequency-value being 1350°C. Cupola tapping temperatures are around 1500°C. Apart from the blowing of premetal for duplexing in the electric-arc furnaces, Witten has, in conformity with its current manufacturing program, taken up the production of direct-poured case-hardening steels, manganese-silicon steels, and chromium-manganese steels with alloy contents up to 3 pct.

Grades required to contain higher percentages of carbon are made by the after-pour process. With this process the LD heat, blown down to 0.1 pct C, is enriched in carbon by the addition of an adequate quantity of liquid cupola iron, slight corrections of the carbon content being made by adding carburizing coal in the ladle. The loss in temperature resulting from the addition of the relatively cold cupola iron

makes it necessary to run these LD heats fairly hot in order to prevent them from losing too much heat.

Slag and oxygen determinations carried out on alloy and plain carbon steels have shown the percentages of oxygen and non-metallic inclusions not to exceed those of open-hearth steel. The oxygen content of the finished blown steel ranges from 0.04 to 0.06 pct. A comparison of the refining slag from the open hearth furnace with that from the LD vessel is found in Table No. II.

Table II. Comparison of Slags from LD Converter and Open-Hearth Furnace

	Composition in Pct					
	FeO	MnO	SiO_2	CaO	MgO	CaO:SiO_2
LD Converter	10.4	6.82	13.70	49.8	6.95	3.62
Open Hearth	15.5	9.60	14.1	44.7	5.0	2.90

LD waste gas cooling and cleaning

To take care of the brown smoke developed when refining with commercially pure oxygen, a dust collection system was provided in the plan for the LD plant. The choice fell on a wet washing system with an electric precipitator capable of cleaning the gas to a dust content of 120 mg per cu m.

The design by Wagner-Biro of the waste gas cooling and cleaning plant is shown in Fig. 8. The boiler has three vertical flues. In the ascending first flue, above the vessel, the radiation-heating system by La-Mont has been installed. The descending second flue contains the grid-type superheater and the preheating coil. The ascending third flue is reversible. When blowing, the flue gases travel through the eddy, cascade, and electrical filters of the filter shaft, entering the chimney flue at 45°C. During the between-blowing intervals, when oil-firing is applied, the flue gas fan, after readjustment of the entry and exit flaps, sucks the waste gases through the narrow shaft. For this purpose the three oil burners in the first shaft are lighted, and the water-cooled flaps below them are shut.

The sludgy water issuing from the lower part of the filter shaft is circulation-cooled and cleaned, so that only the loss by evaporation of 0.5 cu m per melt has to be made good.

For reversing the flaps, regulating the number of revolutions of the flue gas fan, switching on the ventilators of fuel oil, and sludge water pumps, a central boiler-control station, comprising also the surveying instruments and regulators, has been provided for.

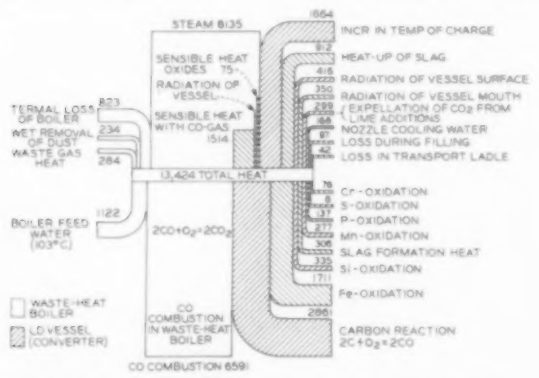


Fig. 9—Heat flow for a 28.8 metric ton charge in the LD converter at Witten. Waste heat boiler produces 12.45 metric tons of steam per heat.

The heat flow of a 28.8 metric tons charge and 88.6 pct yield is shown in Fig. 9. The hatched sections to the right represent the quantities of heat in the melt developed by the burning of carbon monoxide, by the oxidation of the alloying elements, and the formation of slag, together 43 pct. The left hand side shows the heat generated in the waste-heat boiler through the combustion of the monoxide, in addition to the heat supplied by the boiler feed water, together 57 pct. Deducting the indicated losses, the net amount of heat resulting for the boiler is 8.1 million kcal. Based on a steam generating heat of 650 kcal per kg this corresponds to 12.45 metric tons of steam per heat—blowing time 25 min—or 29.9 metric tons per hr. The efficiency resulting from the heat balance is 86 pct.

Estimate of LD cost

So far it is impossible to say what the cost of the LD process is. The actual figure, which will be available after present tests have been concluded, will answer the question of which is more advantageous, duplexing or direct pouring. As was to be expected, with duplexing the current consumption of the electric arc furnace dropped from 832 to 217 kw-hr per metric ton, whereas the consumption of electrodes decreased from 8.5 to 3.3 kg per metric ton.

The production cost of directly poured LD steel of open-hearth quality is not yet quite on a level with that of heats from the open-hearth furnace. It may be anticipated that, apart from duplexing, the gravity center of production will be found in the direct pouring of steels in electric furnace quality. A series of alloy heats in electric furnace quality have already been produced.

Summary

When it was considered necessary to increase the ingot steel production of Gussstahlwerk Witten, the choice fell on the basic hot-blast cupola furnace to serve as a melting unit. Apart from making hot metal available for the open-hearth furnace, the cupola furnace, by way of the LD converter, was to make duplexing in the electric-arc furnace and direct pouring from the LD vessel possible.

The hot-blast cupola furnace has been run on charges differing in composition. The reduction of ores is possible to a limited degree. Enriching the blast with pure oxygen was not a success. A test made with Krupp-Renn pellets pointed to the possibility of using such pellets in quantities of up to 40 pct with a proportional decrease in cost resulting.

The charging of liquid cupola iron in the open hearth steel plant has brought about the expected drop in specific heat consumption and an increase in furnace efficiency.

The use of LD blown steel for duplexing has resulted in a remarkable decrease in the consumption of both electrodes and current in the electric arc furnaces.

The direct pouring from the LD vessel of steels in open-hearth quality is not yet what is desired from the viewpoint of cost. It may be expected that the center of gravity of future production will be found in the direct pouring of steels in electric quality.

[1] See article on page 596 of this issue of JOURNAL OF METALS.

SOLID-STATE PHYSICS CONFERENCE IN LENINGRAD

The roving AIME membership continues to provide the Journal of Metals with reports from the USSR. This time John J. Gilman of General Electric Research Laboratory tells of a recent international conference on "The Mechanical Properties of Non-metallic Solids" which took place in the city by the Neva.

Leningrad Academy of Science on the Neva

by John J. Gilman

IT would be difficult to find a more fascinating place to attend a scientific conference than Leningrad, USSR. Its mixture of Czarist ghosts, revolutionary history, ballet tradition, scars of World War II, and vigorous reconstruction would make it unique, even if it were not in the mysterious and exotic Soviet Union.

Leningrad, formerly St. Petersburg, is now a bustling seaport of four, perhaps five, million population. It was begun as a military fort in the early eighteenth century by Peter-the-Great, who soon established it as the center of government in Russia. Between that time and 1918 it was filled with palaces of all sizes, large government buildings, and great cathedrals. Many of these old buildings have been maintained or restored. Their brightly painted French-style facades form a rich contrast with rather drab brick buildings. All the buildings are uniform in height but very broad in base, and this also contributes towards making Leningrad architecturally unique. Although they are proud of the fact that a newspaper can be read on the bank of the river Neva at midnight in June, most Leningradians agree that the weather is miserably cold and wet. However, they think that this is compensated by their excellent museums (the Hermitage is outstanding), fine theaters (they profess their ballet to be the best in the Soviet Union—I am inclined to agree), and the nearby showplace, the

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Summer Palace of Peter-the-Great. Construction of large apartment houses is the most urgent project in Leningrad at present. During 900 days of German siege the city suffered terribly, but about 3,000,000 sq m of floor space have been repaired or rebuilt, and now the city is being expanded.

The Conference that I attended was entitled, "The Mechanical Properties of Nonmetallic Solids" and was sponsored by the International Union of Pure and Applied Physics and the Academy of Sciences of the USSR. About 150 people attended, but only six of these were foreigners: from Belgium, the UK, and the US. Except for a handful of people from the satellite countries, Soviet citizens made up the rest of the audience.

Although the title of the Conference excluded metals, discussion of them occasionally crept into the program. Also, some of the topics that were discussed are of interest to metallurgists, since many of the principles of mechanical behavior apply to both metals and non-metals.

Academician Joffe, the chairman

The guiding hand of the Conference was provided by the Chairman, Academician A. Joffe, who is well-known in this field for his early work on the mechanical properties of alkali halide crystals, and especially for the *Joffe effect*. He was aided by Professors M. V. Volkenstein and I. M. Kornfeld. The former works in the field of high polymers and so may be unknown to metallurgists, but Kornfeld is known for his work of some years past on recrystallization.

The Conference opened with a historical resumé of his own work by Professor Joffe. He entered the field through an interest of his professor, Roentgen, in piezoelectricity. At that time it was thought that plasticity was due to some kind of high-temperature transformation. During this same period the conflict that existed between Born's theory of cohesion and experiments was resolved by the Griffith flaw theory, and Joffe did his classic experiments which supported Griffith's theory. At the present time, we explain plasticity and fracture in terms of defects in crystals. Joffe expressed the hope that the Conference would consider "the theory of defects and not defects of the theory". He closed by citing what he considers to be the outstanding problems of the mechanical properties field:

1) finding a connection between mechanical strength and chemical bond strength,
2) understanding the role of surfaces,
3) relating electrical and mechanical properties,
4) discovering a theory of mechanical strength that embraces all solids at once; i.e., polymers, metals, and inorganic compounds, and
5) studying the transition from ultrasonic to heat vibrations.

Creep and rupture

The first report of experimental research was by Professor S. N. Zhurkov of the Physical-Technical Institute, Leningrad. The work was of high quality and concerned stress-rupture and steady-state creep measurements. It is of special interest, because a controversial conclusion may be drawn from it, and because of its broad scope. Rupture times and creep rates, which covered ten orders of magnitude in time, were measured with the aid of a high-speed loading machine. Also, a variety of distinctly different materials were studied, including *organic glass*, aluminum, platinum, and silver chloride. It was found that the activation energies for both creep and rupture have the same values and are stress-dependent. At zero stress they are very nearly equal to the heats of sublimation of the materials. Although Zhurkov did not state it explicitly, his work is controversial, because the concensus of other workers is that the activation energies for these processes equal self-diffusion activation energies. The Russian work suggests that this is fortuitous.

Papers on such things as photoelastic patterns in deformed crystals, *elastic-twinning* in calcite, abrasion of diamond, studies of InSb, cleavage of mica, twinning in quartz and Rochelle-salt, and fracture and structure of high-polymers and glass were of interest to various groups of specialists but are probably not of primary interest to metallurgsits.

Deformation

The deformation of beryllium was discussed by Professor R. I. Garber of the Physical-Technical Instiute, Kharkov. He discussed the changes of structure that accompany deformation in terms of *mosaic blocks* about 1000A in size. These are pictured as continually breaking up and sintering back together as deformation proceeds. He thinks that the latent energy after deformation is stored in the surfaces of the blocks.

The effects of high pressures on the ductility of metals was discussed by G. N. Riabinin of the Laboratory of Super High Pressures, Moscow. Interesting diffusive and martensitic phase transitions in thin antimony films were discussed by L. S. Palatnic, Polytechnical Institute, Kharkov. D. M. Vasiliev of the Leningrad Polytechnical Institute discussed measurements of microstresses in deformed steel and aluminum. Ferrite tends to be compressed and cementite extended in deformed low-carbon steel.

Dislocations in crystals

Perhaps the closest attention was given to dislocations in crystals. This subject has been neglected for some time in the Soviet Union, but now there is enthusiastic interest. Professor S. Amelinckx's beautiful pictures of dislocation networks in many crystals were well-received, and the observations of W. G. Johnston and myself on dislocation mobilities made a strong impression. Although she scrupulously avoided calling them by name, Professor T. A. Kontorova discussed the theory of one-dimensional dislocations. She has extended the early work of Frenkel and herself to include the effect of anharmonicity of the interatomic forces. There were also a few reports of the beginnings of etch-pit studies. Finally, a very good film showing growth spirals in action on crystals of paratoluidine was shown by Professor G. G. Lemmlain of the Institute of Crystallography, Moscow.

Electrolytic Zinc Plant, Great Falls; Montana.

CADMIUM PRACTICE AT GREAT FALLS

Cadmium metal, for which the demand has increased many fold in the past several years, is a byproduct of zinc electrolysis. Here is presented the story of cadmium recovery and production in the electrolytic zinc plant of the Anaconda Co.'s Great Falls plant.

by A. I. Alf

CADMIUM is a relatively rare element, but it is closely associated with zinc, and most zinc ores, as well as lead and copper ores containing zinc, have cadmium values.

In the early days of zinc metallurgy little effort was made to recover cadmium in retort smelters. But a large increase in the demand for cadmium since 1935 has forced retort smelters to improve their metallurgy by adjusting the sinter process so as to increase cadmium recovery. Also in recent years an effort has been made to up-grade cadmium-bearing fumes from lead blast furnaces and copper smelting operations, and recover the contained cadmium.

Cadmium is a constituent of practically all zinc concentrates, in quantities varying from 0.10 to over 1.0 pct. In the electrolytic zinc process, cadmium entering the cycle in the zinc concentrate is dissolved in the regular leaching operation and must be removed from the zinc-bearing solution prior to electrolysis. This removal is effected in the purification operation where sufficient zinc dust is added to the zinc leach solution to effect the removal of copper, cadmium, and other impurities detrimental to zinc electrolysis. The resulting precipitate, variously known as purification cake, purification residue, cadmium cake, etc., contains the copper, cadmium, and excess zinc which was used in the purification. This material, referred to here as *purification residue*, becomes the material from which cadmium is recovered as a by-product of the electrolytic zinc process.

This paper is concerned with the recovery and production of cadmium as practiced at the Electrolytic Zinc plant of The Anaconda Co. at Great Falls, Montana.

A. I. ALF is Supt., Cadmium, Indium, and Rare Metals Div., The Anaconda Co., Great Falls, Montana. Presented at the AIME Annual Meeting, New York, February 1958.

Purification residue treatment

Purification residue, as it comes from the filter presses, contains a high percentage of metallics, and it must be partially oxidized before it is leached. For this reason it is transported to a storage area where it is stock-piled in heaps, so that a quick dissemination of the evolved heat from oxidation cannot take place. It remains there for a period of 60 to 90 days, after which time it is reloaded into cars and transported to the Purification Residue Treatment plant.

The partially oxidized residue is leached with spent electrolyte from the zinc and cadmium electrolytic cells containing about 10 pct H_2SO_4. It is supplemented with commercial sulfuric acid, but a slight excess of purification residue is later added to the leaches for complete neutralization of the acid; the leaches are discharged to a Dorr thickener.

The spigot from the Dorr thickener is slightly diluted with water, heated to 70°C, and filtered on a Moore filter, where it receives its first wash. The spigot from the Moore filter goes to an Oliver filter. Cake from this filter is repulped with water and

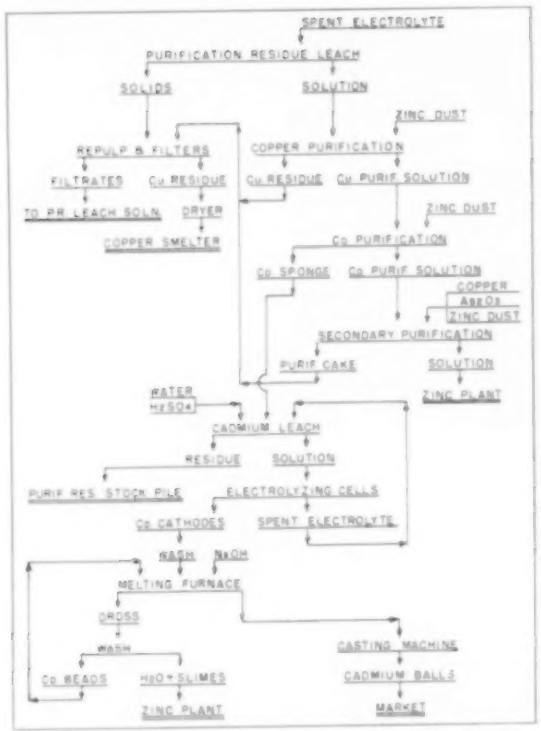

Fig. 1—Purification residue and cadmium plant flowsheet at Great Falls, Montana.

filtered on a second Oliver filter. Cake from the second filter drops onto a belt conveyor and is discharged to a rotary drier. This amount of washing is necessary because washed residue, after being dried, is shipped to the copper smelter at Anaconda, Montana, where any zinc or cadmium in the residue is lost.

The clarified solution from the Dorr thickeners, containing copper, cadmium, and zinc, is pumped to copper purification tanks where the copper is removed by the careful addition of zinc dust. A copper residue is produced which is separated from the copper-free solution in a Dorr thickener, the spigot product being added to the residue from the first Dorr thickener at the Moore filter. Copper-free solution is pumped to cadmium purification tanks where the cadmium is precipitated in sponge form by the careful addition of zinc dust. The cadmium purification sponge is discharged to another Dorr thickener through a small screw-type classifier, which removes cadmium balls that may have been formed during the purification. Cadmium sponge, which settles out in the Dorr thickener, is pumped to a two-leaf American filter and is then transported by belt conveyor directly to the cadmium leaching tanks.

Overflow from the cadmium Dorr thickener is pumped through a heat exchange unit to secondary purification tanks. In this purification, copper (in the form of copper residue), arsenic trioxide, and zinc dust are added to the hot solution and agitated for ½ hr to remove cobalt, nickel, and germanium. The purification tanks discharge to a Dorr thickener, and the spigot is pumped to the Moore filter to join the other residues for washing, drying, and shipment to the copper smelter. The clarified solution is pumped to the Zinc Leaching plant to join the main zinc plant solution flow, thus completing the cycle through the Purification Residue Treatment plant.

Leaching of cadmium sponge

Leaching of the cadmium sponge is carried out in two mechanically agitated wooden leach tanks, 18 ft in diam, and 14 ft in depth. These tanks are completely hooded and equipped with 10,000 cfm Bifurcator fans to exhaust all gases which may be formed during the leaching period. Each tank is also equipped with a foam detecting device, which helps to prevent leach from foaming over the top of the tank. Also, and most important, leach tanks are equipped with an automatic arsine detection and signal system, which is described later.

Head acid for the cadmium leach is prepared in a large storage tank. It is made up to 41 pct H_2SO_4 and contains spent electrolyte from the cadmium electrolytic cells, water, and commercial sulfuric acid. The first step is to fill the leach tank with head acid sufficient just to cover the paddles of the agitator. Then cadmium metallics, consisting of the cadmium sponge balls from the screw classifier, beads, scrap from the electrolytic cells, and slime from the cadmium casting, are added. The mixture is agitated until the metallic cadmium is dissolved. Next cadmium sponge from the American filter is added until the acid content of the leach solution is reduced to near the neutral point. At this point, more head acid is added to the tank, and cadmium sponge is again added until the solution shows neutral. This process of alternating acid solution and cadmium sponge is repeated until the tank is filled to capacity. Enough excess sponge is then added to the leach to completely neutralize all the acid, and to remove any copper, which has been dissolved along with the cadmium. This leaching cycle is generally carried out on day shift.

When the leaching tank is filled, it is agitated for about 16 hr. About 3 hr before it is ready to be discharged, steam is turned on in the tank, and the solution is heated to 70°C. Each tank is equipped with a temperature regulator, which cuts off the steam when the desired temperature is attained and holds it at this temperature. Close temperature control is necessary for elimination of any lead in the cadmium. Before discharging the leach, it is checked for acidity, copper content, and temperature, the agitator is shut down, and the solution pumped through Shriver filter presses. When the tank is almost emptied, the agitator is started again and filtration continued until the leach tank is empty.

Residue from the cadmium leach is sent to the purification residue stockpile to be returned and retreated through the Purification Residue Treatment plant. Filtered solution from the cadmium leach is pumped to storage tanks and fed by gravity to cadmium electrolyzing cells.

Electrolysis

Electrolytic deposition of cadmium is carried out in lead-lined wooden or concrete cells of the same construction as the cells used for the electrolysis of zinc. Anodes are lead-silver alloy, containing 0.5 pct Ag. Cathodes are aluminum sheets welded onto cast aluminum bars, with copper inserts on the contact end of the bar. Bus bars on the cells are made from 1⅝ in., rolled copper.

There are 60 cells in operation in the cadmium electrolyzing cell room; each cell has 37 anodes and 36 cathodes, and spacing is 3 in. from center to center of the cathodes. The cells are divided into eight units, six units of eight cells arranged in double cascades of four cells each, and two units of six cells arranged in double cascades of three cells each. The cell voltage is approximately 2.5 v, and the current density will vary from 2.5 to 3.5 amps per sq ft. Each individual cascade is fed with electrolyte at the top end of the first cell, and spent electrolyte is discharged from the bottom cell of each cascade into a common tank. This solution is recirculated to the cells, by means of a 2 in. Worthington pump. New feed is added to the electrolyte in the recirculation tank, and excess electrolyte overflows the tank into a launder and moves by gravity to the Purification Residue Treatment plant. Feed to the cells contains about 200 gpl Cd, and 65.0 gpl Zn. The spent electrolyte contains about 70.0 gpl Cd and 135.0 gpl H_2SO_4.

Cathodes are stripped of cadmium deposits every 24 hr. Electric hoists lift 18 plates and transport them to a stripping rack. Each workman strips 15 cells, or 540 plates, in an 8-hr shift. Beads and trees on the cathodes are not scraped off, but remain with the cathodes. The cathode sheets are rolled into bundles that can be easily handled, loaded on industrial cars, and delivered to the Cadmium Casting dept.

Melting and casting

The present cadmium melting furnace consists of a welded steel crucible made of $\frac{3}{4}$-in. plate, 36 in. in diam and 52 in. in depth, having a capacity of approximately 15,000 lb of cadmium. Four peripheral gas burners, thermostatically controlled by the heat of the melt, furnish heat to the down-draft furnace. A $1\frac{1}{2}$ ft sq flue from the bottom of the furnace and under the floor is connected to an Industrial Engineering Co., Type PIH-40, Class "M" thermo exhauster, which exhausts the furnace gases to a brick stack. Molten cadmium is tapped from the crucible through 1 in. ID, heavy wall, stainless steel pipe. There are two of these pipe lines from the furnace: one services the ball casting machine, and the other is used for casting shapes, such as sticks or slabs. These metal flow lines are heated by electrical resistance, and temperature is automatically controlled.

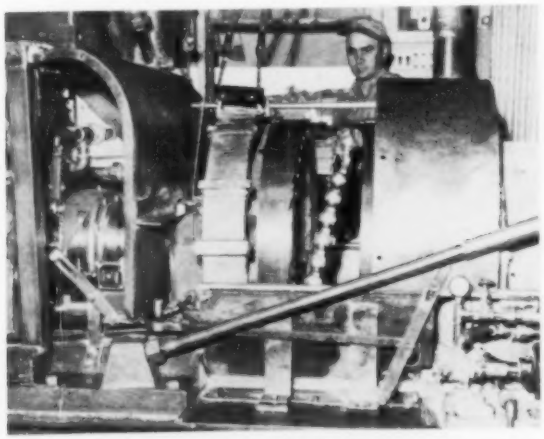

Fig. 2—Centrifugal cadmium ball casting machine.

Cadmium cathodes from the electrolyzing cells are first washed in water and allowed to drain, but not to dry, before they are charged to the melting crucible. About 1500 lb of cathodes are charged at one time. Caustic soda is used as a cover to prevent oxidation. Beads and sprues are also charged with the cathodes. After the cathodes have melted, the caustic dross, which contains some metallic cadmium in the form of prills or beads, is skimmed from the melt, and charged directly into a dross washing machine filled with water. After the crucible has been skimmed, another charge of cadmium cathodes and scrap is added to the melt. This process of melting and skimming is carried on during the time that metal is being cast.

In the pipe going to the ball casting machine there is an automatically controlled valve, which is timed to introduce the correct amount of metal into the rotating ball mold. Initially, the mold is heated to 250°F with a low-frequency water-cooled induction coil. This is connected to a timing device, which starts the induction coil about 2 hr before the working shift begins. When the mold and the metal line are up to the proper temperature, the casting operation is started. Push-button control starts the mold rotating, and when a speed of 596 rpm is attained, a preset automatically controlled valve opens for 5 to 6 sec, which is the time required for filling the mold. The machine motor cuts out when the mold is filled, and the mold coasts to a stop and automatically opens, permitting the removal of the cast balls and the sprue. The total running time of the cycle is $1\frac{1}{4}$ min, and the total elapsed time from start of one cycle to the start of the next cycle is approximately 3 min. The mold is brushed and dressed with Syntholube after each cycle.

The cast balls and sprues drop into a chain-type conveyor and are dumped at a point where an inspector sorts the balls from the sprues. Unacceptable balls and sprues are put onto another chain-type conveyor delivering to the melting furnace. Balls that pass inspection are delivered to a machine where they are washed, first in a weak sulfuric acid solution, and then in water. From the water wash, they roll down a trough through a brushing machine, which is equipped with horizontal steel brushes, one stationary and one rotating. The brushes clean the surface of the balls which discharge to a sloping bench where they are boxed and weighed for shipment.

Cadmium metal is cast at from 750° to 900°F, the ideal temperature being about 840°F. The automatically controlled gas burners keep the molten metal in the furnace within this temperature range. Mold temperature is controlled by air from a Coppus blower. Temperatures of metal in the furnace, in the pouring lines, and the mold are indicated on Micromax meters, and are controlled from these meters. The centrifugally-cast cadmium ball is denser than a hand cast ball, weighing approximately $1\frac{1}{4}$ lb, compared to 1 lb for the hand cast ball, and a centrifugally-cast ball does not contain the sink hole commonly present in hand cast balls. About 6200 lb of balls are produced in the average working shift.

Other shapes, such as sticks, slabs, or anodes, are cast in a conventional manner, with the exception that the metal is drawn from the melting furnace through a metal line, equipped with a manually operated valve, directly into the mold.

Treatment of cadmium dross

Cadmium dross from the melting furnace is charged directly into a drum-type washer made of stainless steel, similar in construction to the dross drums used for the treatment of zinc dross. The drum is mounted on hollow trunions, so that water can be introduced into the drum. During the skimming period, water is allowed to flow continuously through the drum, and most of the hot caustic is dissolved and washed out. After skimming is finished, the drum is closed and rotated for 5 or 10 min, the water is then drained off, and the cadmium metal beads remaining in the drum are washed with spent electrolyte from the zinc electrolyzing cells. When the cadmium beads are clean, the acid is drained off and the washed beads are dumped from the drum into a pan and charged to the melting furnace.

Wash water from the cathode wash, and the wash water from the dross washing drum flow to a common sump. The caustic present in the wash water causes a precipitation of both zinc and cadmium present in the water as hydroxides. This mixture of water and hydroxide is pumped to the Zinc plant by way of the spent acid launder from the zinc electrolyzing cells. Slimes that collect in the sump are cleaned out periodically and retreated in the cadmium leach.

Audible alarm system for the detection of arsine

Wherever hydrogen is generated in the presence of arsenic, there is always the possibility that a very toxic gas may be formed. In the Great Falls plant, workmen receive continuous portection against the possibility of arsine contaminating the working areas. All tanks are properly enclosed and vented by stacks equipped with suitable exhaust fans to move gases from the tanks to the outside air. Flues are equipped with draft gages to check on both the vacuum and volume of air passing through the system. In case of power failure, warning signals are actuated to inform the workmen, and so permit them to evacuate the area until it can be checked.

Working areas, in which there exists the slightest possibility that arsine might be found, are monitored continuously by an apparatus that will cause a siren to sound if even a minute trace of the gas is detected.

The detection device consists of a light source, a bottle of silver nitrate solution through which the light passes, an electric eye which actuates a signal, and a pipe system for collecting samples of air to pass through the silver nitrate solution. Operation of the device is based on the fact that arsine gas will decompose silver nitrate and cause metallic silver to form, thereby darkening the color of the solution. The metallic silver changes the amount of light passing through the silver nitrate solution, thereby actuating the electric eye and sounding a warning siren.

A vacuum by-pass system is used for collecting the air to be tested. By this method, only a small part of the air sampled reaches the silver nitrate solution. However, the sample that does reach the detection device reaches it only a few seconds after it is picked up.

Nominally the detection device serves more than one group of air pick up heads. Ahead of the detection device for each of the groups is a series of four bottles constituting an arsenic train. The first bottle serves as a trap, the second bottle contains a solution of lead acetate to remove hydrogen sulfide, the third bottle contains water and serves as a wash, and in the fourth bottle is a paper impregnated with mercuric chloride which will darken in the presence of arsine. This bottle points out the locale from which the arsine tainted air sample was picked up. Gases that go through the first four bottles go through a fifth bottle containing the silver nitrate solution.

At the sound of the siren, workmen are instructed to evacuate their working areas immediately. The detection device is checked by an authorized person wearing an oxygen mask for the location from which the contaminated air sample was taken, and this person then checks that work area for the cause of the arsine. Not until the working area has been thoroughly checked and found to be safe are the workmen allowed to return.

Air sampling lines from sampling area to the sampling device should not be over 70 ft in length. Approximately 1 to 3 cfm of air is drawn through the sampling line, but only from 50 to 150 cu cm are diverted through the arsenic train. Air from the inlet of the sampling line reaches the bottle containing the silver nitrate solution in 2 to 5 sec. This system of detecting arsine is both positive and rapid, and in our opinion, the best device for its particular purpose.

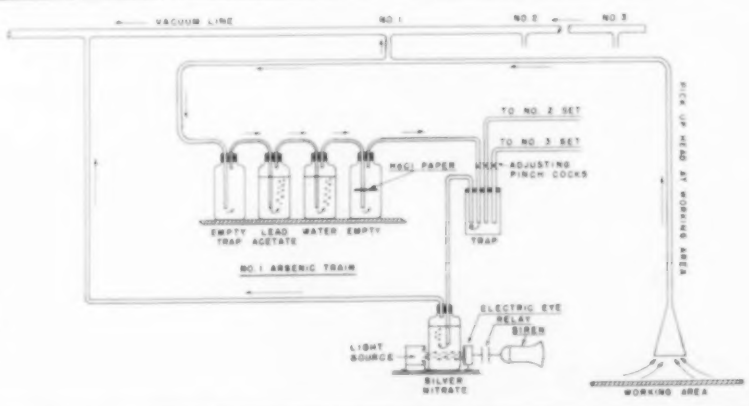

Fig. 3—Vacuum by-pass system for the detection of arsine provides continuous protection for workmen at the Great Falls plant.

EXOTHERMIC FERROMANGANESE

No chilling effect and higher recovery are the two chief advantages which have turned steel producers toward exothermic ferroalloys—a blend of an oxidizing agent, a reducing agent, and a conventional ferroalloy. The reducing and the oxidizing agents, upon contact with the molten metal, produce sufficient heat to deliver the ferroalloy in molten state. Satisfaction has been such that use of exothermic ferroalloys has greatly multiplied since exothermic ferrochrome was introduced in 1939 by the Chromium Mining & Smelting Corp.

Exothermic ferromanganese has found the broadest applications of this group of alloys and was the subject of a special session at this year's National Open Hearth Conference. Below is presented an article on production at the Electro Metallurgical Co., and three conference reports on the use of exothermic ferromanganese: at Youngstown Sheet & Tube, Bethlehem Steel, and U. S. Steel.

Production by W. R. Lewis

The variable melting conditions in the open-hearth bath result in unpredictable and erratic losses of manganese additions. Hence, most operators prefer to add as much manganese as possible to the ladle where they can obtain closer manganese control and higher recoveries. Heavy additions of regular ferromanganese alloys, however, cannot be made to the ladle without severe loss of temperature and abnormal segregation.

With exothermic manganese alloys, steelmakers can add as much as 2 pct Mn to the ladle with little temperature drop and no danger of segregation. The exothermic reaction supplies heat and promotes stirring within the ladle, providing for a uniform distribution of manganese. In addition, the heat evolved permits the material to be added conveniently to the bottom of the ladle before tap, thus avoiding the problems involved in making additions during the tapping of a heat.

What is it? Exothermic manganese is a mixture of a properly sized ferromanganese alloy and materials that provide the exothermic reaction. The materials in the reaction are so balanced that the reaction goes to completion and will produce enough heat to melt the mass of alloy and minimize temperature loss. The particle size of the components, the heat generated by the reaction, and the turbulence resulting from the reaction are all factors promoting rapid solubility and uniform distribution of manganese. For convenience, the material is packed in cans containing exact weights of the manganese and carbon additions.

There are two basic types of exothermic reactions among the special addition products currently on the market. One is a reaction of aluminum and sodium nitrate which forms sodium aluminate. The other is a reaction of silicon and sodium nitrate which forms sodium silicate. The products of both reactions pass off in the slag.

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Electro Metallurgical Co. produces exothermic ferroalloys which are based on the aluminum-sodium nitrate reaction. Typical compositions for high- and medium-carbon grades of exothermic ferromanganese are shown in Table I.

How is it produced? Regular lump manganese alloys—standard ferromanganese for the high-carbon grade and medium-carbon ferromanganese for the medium-carbon grade—are crushed to 20 mesh in a rotary-type crusher. The crushed manganese is then weighed and mixed in an Abbe blender with the materials making up the exothermic reaction, Fig. 1. The reaction materials—sodium nitrate and aluminum powder—are added in stoichiometric proportions. A relatively small amount of aluminum and sodium nitrate is needed to give the heat required, with the result that not much slag is formed, and the fume from the mixture reaction is reduced.

Also added to the materials in the blender are fluorspar and a natural wood resin binder. Fluorspar increases the fluidity of the slag formed by the end products of the exothermic reaction and acts as a reaction accelerator, increasing the rate of solution of the mixture so that the alloy will dissolve early in the tap and have more opportunity to become uniformly distributed throughout the melt. Fluorspar also increases the amount of heat given off by the reaction, thereby reducing the amount of the reaction materials needed.

The resin binder serves to hold the materials together in a briquet in a subsequent heating operation. But this binder also contributes to the agitation and stirring of the molten steel when the alloy dissolves, effectively preventing floaters and segregation.

Fig. 1—left—Weighing and mixing ingredients for exothermic ferromanganese at the Alloy, W. Va., plant of Electro Metallurgical Co., div. of Union Carbide Corp.

Fig. 2—right—Oven for heating exothermic ferromanganese cans. Resulting briquet prevents loss of fines within the ladle.

After blending, the exothermic manganese mixture is poured into cans and weighed semi-automatically. The cans contain weights of manganese and carbon as follows:

	Total Weight, Lb	Mn, Lb	C, Lb
High-Carbon Grade	64	40	4
Medium-Carbon Grade	58	40	0.8

These cans are carefully checked for weight and analysis before further processing. The tops are then sealed on and the cans are placed on flat cars, which are rolled into a batch-type oven for heating at approximately 350°F for 7 hr. The heat melts the resin binder, forming a briquet. This briquet prevents loss of fines within the ladle and gives more uniform recoveries, Fig. 2.

When the cans are removed from the oven, they are packed on pallets holding 60 cans or approximately 3480 lb of material for the medium-carbon grade and 3840 lb of material for the high-carbon grade. There pre-weighed cans allow easier handling and eliminate weighing in the steel plant. The pallets are a further aid to handling because they can be moved easily by fork lift truck or overhead crane. The entire pallet can be added to the empty ladle by crane, or where less than a pallet is required, the cans can be counted to determine weight and added individually. To facilitate identification, cans are color coded according to grade.

The capacity of Electromet's newly built exothermic manganese plant is in excess of 1000 tons per month. Some steelmakers believe that, as they gain more experience using exothermic manganese, there will be a steady increase in the use of the alloy until a major portion of high-manganese steels are produced using this type product.

Table I. Composition of High- and Medium-Carbon Grades of Exothermic Ferromanganese Produced by Electro Metallurgical Co.

	High-Carbon Grade	Medium-Carbon Grade
Mn, pct	62.6	69.0
C, pct	5.9	1.10
Al, pct	3.6	3.7
$NaNO_3$, pct	7.0	7.0
CaF_2, pct	4.25	4.25
Total C, pct	6.5	2.1

Results at Youngstown

by R. L. Kimberly

The only justification for using exothermic manganese is to allow the manganese addition to be made in the ladle. It is well recognized that ladle additions of manganese have one advantage over furnace additions, i.e. a much more uniform manganese recovery. This is particularly important for steels over 1.00 pct Mn which are always troublesome from the viewpoint of analysis. Greater uniformity of recovery resulting from manganese ladle additions should bring about fewer off-heats.

At various times in the past, ladle additions of at least part of the regular ferromanganese have been tried, but always, the thermal limitation of adding a large cold mass of material to the ladle has forced us to abandon the practice. Given a shady heat or a slow tap, and many times with no apparent reason at all, manganese floaters will form, causing high tail-end pickups in manganese.

Present practice is to block with silicomanganese —the 65 pct Mn grade—and put all the regular ferromanganese through the furnace, with the possible exception of a few hundred pounds in the ladle to allow for necessary recovery corrections.

To justify the use of exothermic manganese, we must show two things:

- Exothermic manganese gives a more uniform recovery, and
- There is no tendency to show tail-end ingots high in manganese.

Manganese addition for the exothermic practice at the Indiana Harbor Works of Youngstown Sheet & Tube is calculated on the basis of a 4000 lb silicomanganese block—about 45 points at 80 pct recovery —and a regular ferromanganese addition of about 3000 lb or 40 points of manganese, an amount which the addition chutes can comfortably handle. The

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balance of the manganese is added to the bottom of the ladle as exothermic material. Any correction for heat size or recovery is made by varying the weight of the regular ferromanganese in the addition chutes. Our heat size averages 235 tons.

We are a little past the half way point in our test of 100 heats using exothermic manganese. Data presented is based on the first 54 heats, and for comparison, 39 heats were selected which were made according to the regular practice of putting the manganese through the furnace. Both groups of heats were made during the same period of time.

In order to avoid spreading the data too thin over too many variables, the test has been limited to three specifications. These are shown in Table II. Although some variation has been noted between grades, this difference is not enough to prevent lumping the data together to give a larger picture. In order to give the strictest test, all data has been equated to the 20 point manganese range of the N-80 grade.

The average recovery of the 39 heats made with regular manganese through the furnace practice is 75.3 pct, which is about the average on all high manganese grades blocked over 0.20 pct C and made to this practice. The 54 heats made to exothermic practice average 80.4 pct recovery or 5.1 pct higher.

The spread of recoveries can be shown by the graph in Fig. 3. This is a frequency distribution of recoveries. Along the abscissa are plotted recoveries grouped and at class intervals of 4 pct, while the percent of heats falling in each group are plotted along the ordinate.

The high point or mode of the exothermic curve is 40.7 pct of the heats falling into the 80 to 83 pct recovery class compared to 28.2 pct of the heats falling into the 76 to 79 pct class for regular practice. Exothermic distribution is definitely more narrow with a higher peak, than the squat, spread-out curve resulting from the regular practice. These attributes of recovery distributions show the greater unifomity of recovery yielded by exothermic manganese.

This consistency of recovery can be demonstrated in still another way. On an N-80 seamless tube heat, on which the avg recovery of 75.3 pct is figured for regular practice, the lowest efficiency which can be obtained and still have the heat finish within range is 70.1 pct. Likewise, an efficiency of 80.4 pct is the highest efficiency which can be tolerated to put the heat in on the high side. It is found that only 59 pct of the heats made according to the regular practice fall into this range of 70.1 to 80.4 pct.

Applying this same test to the exothermic manganese practice, where the avg recovery of 80.4 pct is used, it can be shown that any heat falling into the 74.8 to 85.9 range will finish within the chemical limits set for manganese. Of all the heats made to the exothermic practice, 81.5 pct of them fall into this range, or 22.5 pct more than heats made to the regular practice.

As was mentioned earlier, one of the principal objections to ladle additions of manganese has been the high spread in ladle manganese from the first part of the heat to the last part. This characteristic of ladle additions almost disappeared during the test. Average spread on ladle analyses was .047 pct Mn on regular practice heats, compared to .052 pct Mn on exothermic heats. Only one heat of the 54 exothermic heats exhibited a bad manganese tail up, and there was enough in the way of bad practice so

Table II. Specification of Heats for Youngstown Sheet & Tube Co.'s Test Program

Specification	Mn Analysis Range, Pct	No. of Heats: Exothermic Mn Ladle Practice	No. of Heats: Regular Mn Furnace Practice
N-80 Seamless Pipe	1.45 to 1.65	31	8
1036 Sucker Rod	1.25 to 1.50	17	26
1300 Series	1.60 to 1.90	6	5
Total		54	39

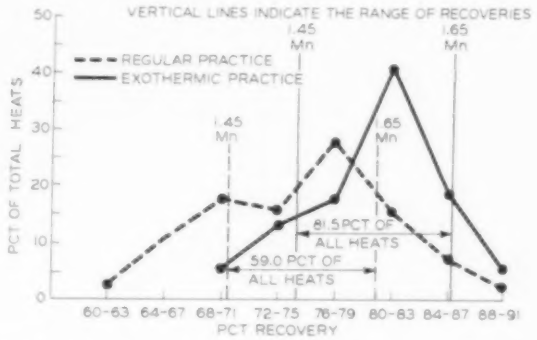

Fig. 3—Frequency distribution of manganese recoveries from regular and exothermic practice at the East Chicago, Ind., plant of Youngstown Sheet & Tube Co.

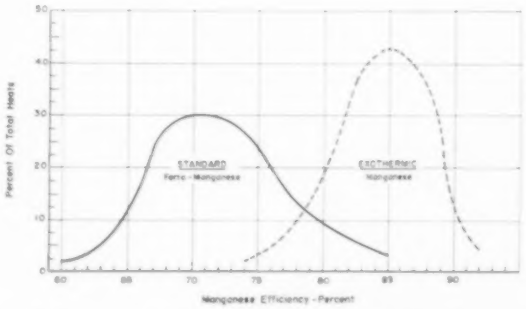

Fig. 4—Frequency distribution of manganese efficiencies from exothermic and standard ferromanganese operations at Bethlehem Steel Co.

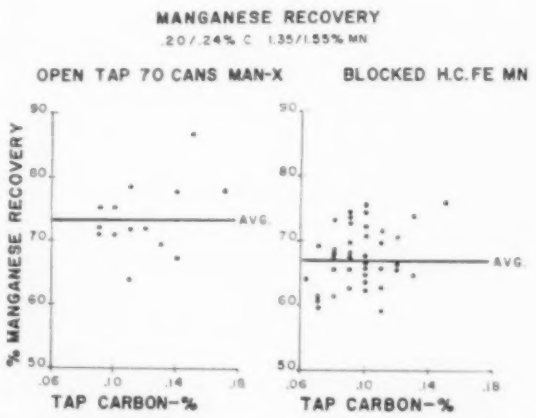

Fig. 5—Spread of manganese recovery for exothermic ferromanganese (left) and high-carbon ferromanganese practice (right) at South Works of U. S. Steel Corp.

that it may be discounted as non-representative. Whatever recovery variations there are in the exothermic practice, are probably due to manganese introduced in the furnace as silicomanganese, for about 30 pct of the manganese is still introduced in the furnace by this material.

Exothermic material is, of course, more expensive, although the 5 pct difference in recovery pays for a little over half the additional cost. Costs are further reduced by fewer off-heats. When the strict test of the 20 point range is applied, the off-heat picture does not live up to what might be expected from the frequency distribution. Exothermic manganese accounts for only a 10 pct cut in off-heats, but we believe that as experience is gained this picture will improve. On the other hand, if the looser 30 point manganese range of the 1300 series is applied exothermic manganese cuts off-heats by 35 pct. Generalizing, it can be said that heats are still missed by exothermic manganese, but they aren't missed quite as badly and, after all, it is the severely missed heats that wind up in the bone yard!

Results at Bethlehem

by T. V. Wainwright

Bethlehem Steel Co. has used exothermic ferromanganese mainly to make AISI 1330 and 1335 grades. It was first used in an attempt to obtain more consistent recoveries, and, hence, less chance of off-grade analyses. The distribution curves in Fig. 4 show that the spread was not as great for exothermic ferromanganese as for standard ferromanganese and also that the distribution was more uniform. Recovery was better and more consistent—84 pct recovery as against 72 pct for standard ferromanganese. Both aluminum and silicon containing alloys are included because both types had about the same recovery and distribution.

To control grain size, aiming for McQuaid Ehn 5 to 8 or better, extra aluminum had to be added when using the exothermic material. This amounted to about $\frac{1}{2}$ to $\frac{3}{4}$ lb per ton. Pick-up of nitrogen on these grades amounted to 0.003 pct.

No difference in quality was noted between the product treated with the exothermic material as compared to that with standard ferromanganese addition.

It was concluded from our experience that, if there is difficulty in obtaining the specified manganese analysis, the use of exothermic manganese can help, but at an increase in cost.

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Results at US Steel

by W. A. Olsen

Development work was done at No. 2 Open Hearth Shop, South Works of U. S. Steel Corp. This shop contains fourteen 135-ton furnaces, and the area behind the furnaces is restricted; therefore, very limited amounts of stock can be added during tap unless the material could be added to the bottom of the ladle prior to tap. Consequently, use of exothermic ferromanganese seemed attractive from the standpoint of addition.

Table III illustrates the chemistry ranges of the semi-killed and killed *MAN-TEN* steels produced, and also the weight ranges of the additions.

The hazard of manganese floaters caused by a large addition on the ladle bottom is well known. Consequently, some balance between exothermic material and cold stock had to be determined. Since the exothermic material is a higher priced additive, it was desirable to keep this addition as low as possible.

With semi-killed steel, additions of 2400 lb exothermic manganese with 3000 lb high-carbon ferromanganese proved unsatisfactory as did 2600 lb of exothermic manganese. Variations of almost 2 pct Mn were encountered between the ladle test taken at the first 10 pct of the heat and the ladle test taken on the last ingot. However, 2800 lb of exothermic manganese and approximately 2700 to 2800 lb of standard ferromanganese resulted in a satisfactory chemistry balance. Manganese increased at the end of the heat with the exothermic manganese practice and decreased with the standard practice.

The killed MAN-TEN, which had a similar cold stock addition, also had satisfactory chemistry performance.

When comparing the conformity to specifications of the two practices, the spread of manganese seems excessive. However, Fig. 5 shows that the efficiencies, besides being higher with the exothermic material, are generally more consistent. Therefore, with additional experience, manganese performance should improve. It should be noted that the lowest efficiency of the exothermic manganese is, in all cases, greater than the lowest efficiency of manganese using the standard practice. It can be concluded that exothermic manganese definitely makes heavier ladle additions possible without the erratic chemistry performance usually encountered.

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Table III. Specifications of Heats for U. S. Steel Corp.'s Test Program

Composition	Exothermic Practice		Regular Practice	
	Furnace Addition	Ladle Addition	Furnace Addition	Ladle Addition
0.20 to 0.24 pct C 1.35 to 1.55 pct Mn 0.15 pct Si	none	2800 to 3000 lb 76 pct H.C. FeMn 2400 to 2800 lb Exo. FeMn* 300 lb 50 pct FeSi	1000 lb 15 pct FeSi 1000 lb 66.5 pct SiMn 5800 lb 76 pct H.C. FeMn	200 lb 76 pct H.C. FeMn
0.18 to 0.22 pct C 1.15 to 1.30 pct Mn 0.15 pct Si	none	1400 lb 76 pct H.C. FeMn 2800 lb Exo. FeMn* 1500 lb 50 pct FeSi	1000 lb 15 pct FeSi 1000 lb 66.5 pct SiMn 4500 lb 76 pct H.C. FeMn	300 lb 76 pct H.C. FeMn 1100 lb 50 pct FeSi

* Weight represents pure manganese content.

HIGH–PURITY CALCIUM

Calcium metal of high purity, important in the massive preparation of high purity uranium, has been made by fractional distillation process. Calcium so prepared has less than 1 ppm Mg and is better than 99.95 pct pure.

by W. J. Mc Creary

IN a program to prepare massive high-purity uranium metal by the reduction of UF_4 with calcium, it was considered necessary that all reactants in the process be of very high purity.

The purest calcium available at the start of this program was that produced from crude distilled metal by a single-step distillation.[1] Table I is a typical analysis of such metal.

The work of Lee and Susano[1] describes in detail the apparatus and procedures of a single-step distillation of calcium and was the primary reference for the present work.

In a one-step distillation, most of the magnesium in the charge would be expected to transfer to the condenser during the early stages of the distillation, and in order to obtain a product low in magnesium, a mechanical separation of the condensed metal would be necessary. In order to avoid this situation, the process was carried out as a discontinuous fractional distillation, in which successive fractions were collected on a condenser and removed from the system.

The apparatus and procedures which are described in this paper have been in use in the Los Alamos laboratory for about six years and have been used to prepare high-purity calcium on a small scale, not only for the preparation of high-purity uranium metal but also for many other uses.

Raw materials and apparatus

The calcium that was used was produced by the New England Lime Co. and was redistilled at the Y-12 plant of Union Carbide Nuclear Co., Oak Ridge, Tenn. The metal was received in the form of small pellets.

The assembled apparatus is shown in Fig. 1. The retort was fabricated from Type 347 stainless steel tubing, 5 in. OD x 30 in. long, with a plate welded at the bottom and a flange at the top. The flange had two "O" ring groves: one to seal the lid, and the other to seal the retort assembly to a dry-box.

The lid contained a sight glass and a vacuum seal that allowed the condenser to be moved at will. Details of the seal are shown in Fig. 1.

Saunders-type valves were arranged so that the retort could be isolated from the pumping system and inert gases could be added to the retort. A Phillips gage was used to determine the system pressure at high vacuum, and a Wallace and Tiernan differential pressure gage indicated the retort pressure during distillation.

The pumping system consisted of a high-speed mechanical pump and an oil diffusion pump. Dow-Corning Silicone 703 was used as the diffusion pump fluid.

The condenser for collecting metal was fabricated from a 1 in. OD, 0.035 in. wall, Type 347 stainless steel tube, with a plate welded at the bottom. The tube was polished to permit a vacuum-tight sliding seal at the lid. The condenser was cooled by a water-cooled copper cold finger.

A dry box was modified to receive the retort after a distillation. The outer "O" ring on the retort lid made an air-tight seal with a flange on the dry box port.

A crucible of Type 347 stainless steel was used to contain the raw metal.

A cylindrical baffle unit, consisting of parallel semi-circular plates, stacked alternately, was used to aid in reflux and to prevent lime dust from hitting the condenser. The baffle plates were spaced ½ in. apart and were held in place by four vertical rods welded to the plates.

The retort was heated with a 5 in. ID x 24 in. long resistance furnace, hinged for opening. Since the furnace was designed for horizontal operation, the

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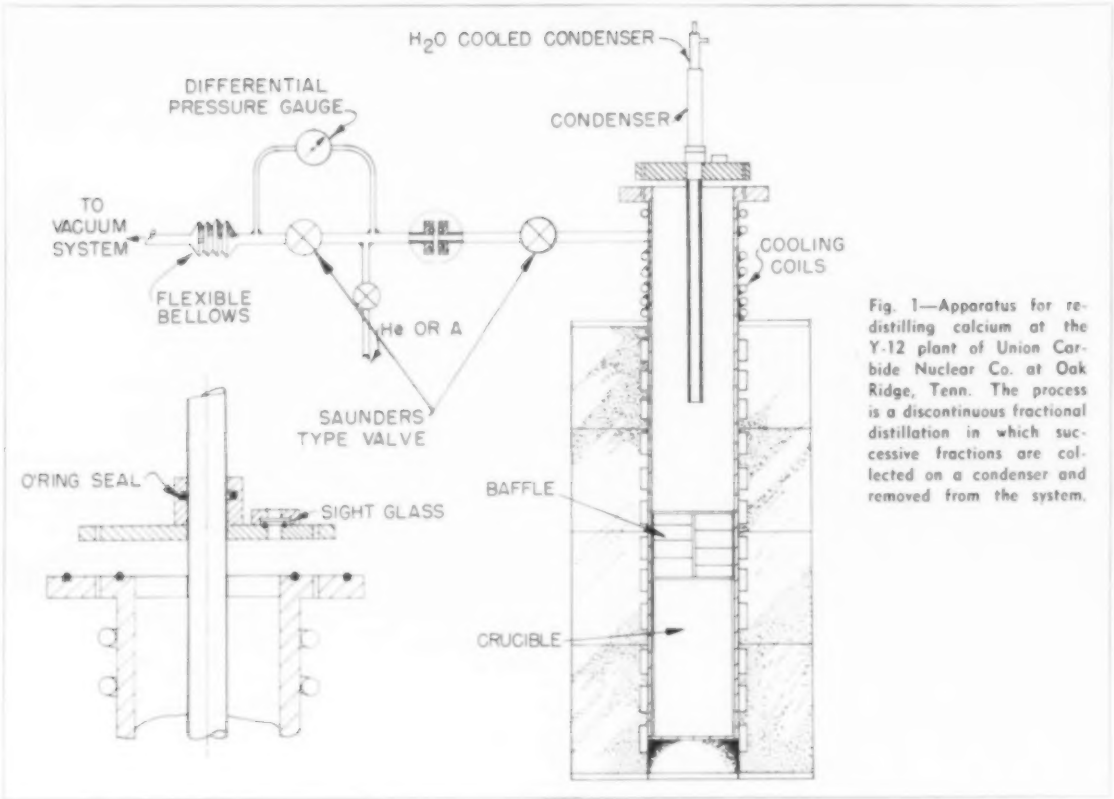

Fig. 1—Apparatus for redistilling calcium at the Y-12 plant of Union Carbide Nuclear Co. at Oak Ridge, Tenn. The process is a discontinuous fractional distillation in which successive fractions are collected on a condenser and removed from the system.

Table I. Analysis of Crude Calcium, Ppm

Li	0.2	Si	<1	Cu	<3
Be	<1*	V	<10	Zn	<100
B	<1	Cr	<3	Ag	<0.1
C	50**	Mn	45	Sn	<1
Na	<1	Fe	5	Pb	<1
Mg	300 to 3000	Co	<3	N	175**
Al	<3	Ni	<3		

* The "<" symbols indicate the lower limit of detection of the element.
**C and N by chemical analysis, the rest by spectrographic methods.

Table II. Results of Distillation of Calcium. Carbon and Magnesium Contents, Ppm

Fraction	0	1	2	3	4	5	6
C	95	90	65	50	25	50	35
Mg	300	300	150	100	3	<1	<1

Table III. Analysis of Distilled Calcium Product, Ppm

Li	<0.1	V	<10	Zn	<100
Be	<1	Cr	<3	Ag	<1
B	<1	Mn	50	Sn	<3
Na	0.4	Fe	<3	Pb	<2
Mg	3	Co	<5	C	38
Al	<2	Ni	<3	N_2	<10
Si	<2	Cu	<1	O_2	0.02±0.03 pct*

* Analysis by Mary Kline using method of A. R. Eberle, M. W. Lerner, and G. J. Petretic, *Anal. Chem.*, vol. 27, p. 1431, 1955.

heating elements were embedded in alundum cement to prevent their sagging when heated in a vertical position.

High vacuum used

The crucible, containing about 1 kg of calcium, was placed in the retort and covered with the baffle plate assembly. After the retort had been closed with the lid assembly, it was connected to the pumping system and outgassed at about 350°C to a pressure of 0.02μ Hg. The condenser was adjusted so that the lower end was about 6 in. above the baffle plates. The retort was then isolated from the pumping system and was filled with helium to a pressure of 1.5 to 2.0 mm of Hg. Temperature was then increased rapidly to 850° to 950°C, the pressure being maintained at 2 mm of Hg. The progress of a distillation could be observed through the sight glass in the lid. Generally, a satisfactory deposit was formed in 30 min at the maximum temperature. If the deposit became too large, the outer crystals of calcium melted, and a solid shell formed around the deposit, making it very difficult to remove the metal. When this occurred, the cold finger was removed to allow the metal to melt away from the condenser, after which the condenser was again cooled to collect a deposit.

Condensed metal in crystals and granules

When a satisfactory deposit had formed, the furnace was opened and cooled rapidly. The retort was filled with helium to atmospheric pressure, removed from the system, and attached to a dry box filled

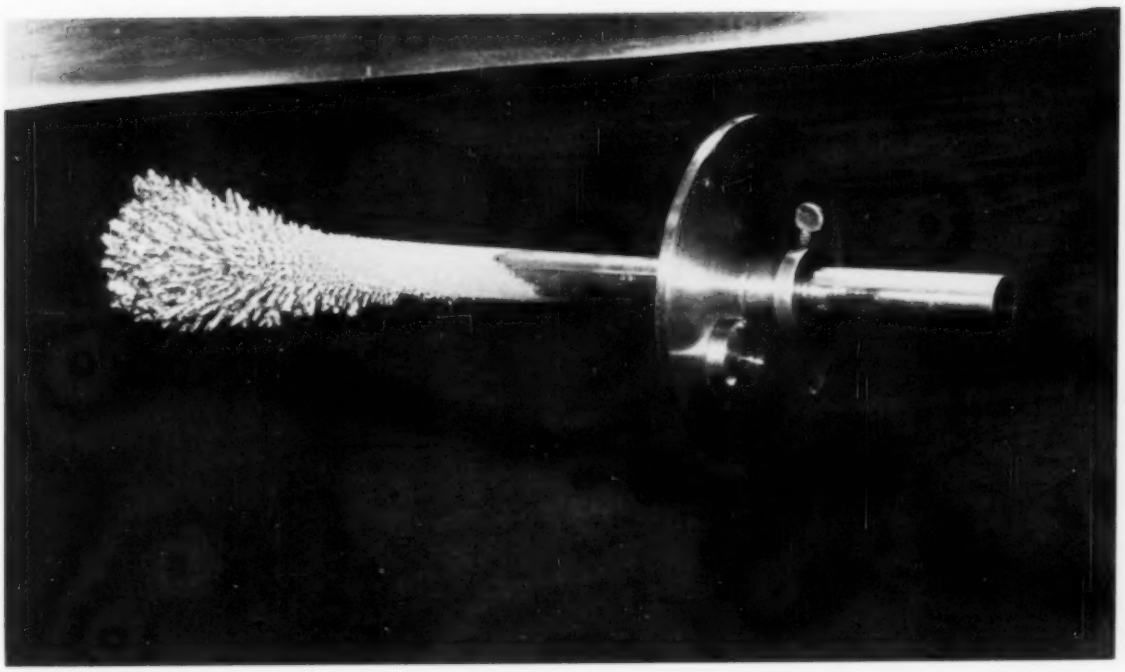

Fig. 2—A typical calcium deposit from Oak Ridge distillation unit. The outer metal is in the form of long, slender, single crystals, while the inner metal is in the form of small granules.

with inert gas for unloading; a typical deposit is shown in Fig. 2. The outer metal, in the form of long, slender, single crystals, attached at one end, was easily removed with pliers. The average size of these crystals was 5 x 0.7 cm. An inner layer of metal was in the form of small granules and was also easily removed. An average deposit contained about 100 g of calcium. The metal was loaded in screw-cap jars, which were then flushed and filled with helium and sealed.

After unloading, a clean condenser was attached to the lid, the retort was re-assembled, and the above operation was repeated. Two distillations could be made in one 8-hr day.

In an attempt to increase production of distilled calcium, a multiple condenser retort was fabricated. This retort consisted of a cylinder, 12 x 12 in. with a 5 in. OD x 27 in. long cylinder welded eccentric to its bottom plate. The lower cylinder contained the charge. The lid of the upper cylinder was sealed with an "O" ring to the cylinder flange. The lid had four condenser ports, each similar to that shown in Fig. 1, and located so that by rotating the lid any one condenser could be aligned with, and lowered into, the lower cylinder. With this apparatus it was possible to collect four separate fractions without cooling the retort. However, the apparatus was abandoned when it proved to be very difficult to rotate the lid without leaking air into the system.

In general, six to nine operations were necessary to distill the original charge. A small amount of metal was lost by condensation on the upper walls of the retort and high up on the condenser. Some of this material was in the form of finely divided metal and, if allowed to come into contact with air, it would burn with explosive violence.

An operating pressure of about 2.0 mm of Hg was considered to be optimum. At pressures below this the deposit consisted of finely divided and very reactive metal. At pressures above 2.0 mm the distillation rate was considerably slower and the metal crystals were small and reactive.

Results

The change in carbon and magnesium content during a typical distillation is shown in Table II. The concentrations of other elements were essentially constant. Metal of the purity shown in Table III was obtained in 35 to 40 pct yield.

Only the large outer crystals of calcium were saved. Analysis of the inner layer of calcium from the first fractions indicated a magnesium content as high as 1 pct. The composition of the inner layers from later fractions was essentially the same as the outer crystals.

The magnesium content of the calcium produced by this method was much lower than that of any calcium reported in the literature to date.[2,3,4,5]

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DUCTILE VANADIUM
A New Engineering Material

Vanadium—discovered in 1801 and used as an alloying element for steel since the early years of this century—was produced in the pure form for the first time in 1927. A semi-commercial process for producing vanadium was not developed until 1950, and today research efforts are being extended to widen the potential market for this new metal.

by T. W. Merrill

MANUEL del Rio, Professor of Mineralogy at the School of Mines, Mexico City, is credited with discovering vanadium in 1801. Choubley, Director of the steel works at Firminy, France, is said to have been the first to add vanadium to steel as a hardening element, although the armor plate he produced in 1896 was apparently not up to present standards.

In 1905 Antenor Patron, a mining engineer from Lima, Peru, discovered a new mineral, the first commercial ore, high in the Peruvian Andes. The discovery of ore containing the mineral bearing his name, patronite, was the origin of the vanadium industry. Title to the deposit was secured by the Flannery brothers, who formed the American Vanadium Co. Later, this company was to become the Vanadium Corp. of America.

In 1927, Marden and Rich announced production of 99.3 to 99.8 pct vanadium metal in the form of ductile globules or shot. In 1939, Van Arkel produced metal of higher purity by thermal decomposition of the iodide.

It was not until 1950 that McKechnie and Seybolt at the General Electric laboratories developed a method of making pure vanadium in massive form in quantities sufficient to permit fabrication into bars, plates, rod, wire, and foil.

We are now in the exploratory stages of studying this new ductile metal to find its proper place in the growing family of reactive metals. There are already some promising applications, and several commercial producers are making it. As a commercial constructional material, however, the star of ductile vanadium has not yet really risen above the horizon.

At the moment more can be said about the raw materials, their beneficiation and reduction to metal, than about properties and uses of the metal and its alloys.

Sources of ores

The most important vanadium ores known are found in the Western Hemisphere. They include carnotite, roscoelite, vanadinite, and patronite. Of these, carnotite is of the greatest commercial importance at the present, not only because it has been found in important amounts in Colorado, Utah, Arizona, and New Mexico, but also because of its other important constituent, uranium. While vanadium ores have been mined in Australia, Africa, Spain, the USSR, Argentine, and particularly Peru, by far the largest tonnage is mined in the US.

Peak world vanadium output has been estimated at about 4500 metric tons in 1943, excluding that produced in the USSR. Consumption was largely in the form of ferrovanadium. In the US the demand for vanadium alloys and chemicals has not exceeded the supply for the last several years, primarily due to the demand for uranium.

Economical recovery from residuals

There are several other sources of vanadium that may assume importance should the demand become great enough. These include: ash from petroleum originating in Venezuela, the Netherlands West Indies, and certain parts of the US; slags from blast furnaces using any of the vanadium-containing iron ores, such as those from Chile; and the phosphate rock of Idaho and Montana.

Although percentages of vanadium in oil, iron ore, and phosphate rock are small, immense quantities might well be made available, if economical recovery processes were developed. It can be said now that such prospects appear encouraging. The point to be made is that, when and if demand for ductile vanadium increases, sources of supply should not lag far behind.

Extraction methods

The method most widely used to extract vanadium, as the pentoxide V_2O_5, from carnotite ore is known as the roast-quench-leach process. This involves crushing the ore to a size less than 10 mesh and roasting it with sodium chloride in a multiple hearth furnace at 1500° to 1560°F to form the water soluble sodium metavanadate, $NaVO_3$. This is followed by quenching the hot ore in water or soda-ash solution, which is then carefully adjusted in acidity with sulphuric acid to cause precipitation of sodium hexavanadate, $Na_4H_2V_6O_{17}$.

There is a complete separation of uranium and vanadium when both are in solution. Very conveniently, the sodium hexavanadate and the sodium uranate precipitate from the solution at different levels of acidity. Modifications of this method are being studied to increase recovery and to lower costs, but this time-tested process is still the most widely used.

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When dried, sodium hexavanadate is commonly known as *red cake*. It contains 85 to 90 pct V_2O_5, 6 to 10 pct Na_2O, and about 3 pct H_2O. Further chemical treatment of the red cake results in the pure oxide. For the reduction of alloys by smelting, red cake is fused and cast into flake form.

Reduction methods

Vanadium's comparatively recent appearance as a pure metal is a good indication that its reduction is not easily accomplished. Because the term *pure metal* is becoming less precise all the time, it is more accurate to say *ductile metal*. Until recently, it had been believed that vanadium was a brittle metal, and therefore of little use as a constructional material. Now, however, it is apparent that a difference in purity of only a few hundredths of a percent determines whether vanadium is brittle or ductile. From the standpoint of ductility the most critical impurities are oxygen, nitrogen, and hydrogen. A suitable reduction process, then, is determined in effect by the levels of these elements in the resulting metal.

Vanadium combines so readily with oxygen and nitrogen that a metal that is even more reactive is required to accomplish a complete reduction of vanadium oxide. Carbon, silicon, or aluminum can be used as a reducer to produce ferrovanadium, but undesirable residual amounts of the reducer are left in the alloy. Only calcium has been used successfully to reduce the oxide to metal, leaving impurities sufficiently low so that the metal is ductile.

There are presently four ways to make vanadium metal. Of these only two are used commercially. A third is a rather elaborate and expensive way of refining the metal to the present extreme of purity. The fourth is a commercial process, resulting in a low cost but brittle metal of relatively low purity.

Calcium reduction

The best known process, and the one used in this country, is the calcium reduction of the oxide as developed by McKechnie and Seybolt. This consists of charging pure vanadium oxide, calcium metal, and iodine into a heavy-walled steel cylinder or bomb, and taking special precautions to eliminate moisture in the charge. The reaction is initiated by the application of heat. Very high temperature and pressure are reached within a short time, sufficient to allow the molten droplets of vanadium to collect beneath the calcium oxide-calcium iodide slag and to form a single button or regulus. After cooling, the chamber is opened and the metal is cleaned of slag by leaching. A typical analysis of the product is: 99.7 pct V, 0.10 pct O_2, 0.04 pct N_2, 0.008 pct H_2, 0.04 pct Fe, and 0.03 pct C.

Magnesium reduction

Two years ago, Messrs. Foley, Ward, and Hock of Magnesium Elektron Ltd., in England, announced the start of a pilot operation producing 40 to 45 lb batches of vanadium. Their process is the magnesium reduction of vanadium trichloride in an atmosphere of argon at a temperature of 1550°F. The reduction step is similar to the Kroll process presently used to reduce titanium tetrachloride to titanium sponge. The physical nature of the vanadium product is similar to titanium sponge.

Probably the most difficult part of the process is the production of the vanadium trichloride. Foley, Ward and Hock chlorinate 80 pct ferrovanadium to produce vanadium tetrachloride and oxytrichloride. The tetrachloride is converted to the trichloride by heating under reflux in a stream of carrier gas. At the end of the reaction the oxytrichloride is distilled off.

The vanadium sponge must be separated from the magnesium chloride and excess magnesium by melting under argon, then by heating under vacuum to 1650°F, and finally by leaching. A typical analysis of the sponge is said to be: 99.7 pct V, 0.12 pct O_2, 0.005 pct N_2, 0.01 pct H_2, 0.01 pct Mg, and 0.03 pct Fe.

Highest purity refining

The purest vanadium yet produced results from a refining process credited to Van Arkel. The process begins with the metal rather than the oxide, halide, or other compound. In most of the work done to date, vanadium of the purity obtained by one of the processes described above has been used. This fact, plus the nature of the process, will give a hint of the cost of the resulting product.

First, vanadium tri-iodide is formed by reacting iodine vapor and vanadium metal in a heated and evacuated chamber. In the center of this chamber, which is made of quartz or pyrex glass in the laboratory apparatus, is a loop of fine vanadium wire heated to incandescence by electric current. The vaporized vanadium iodide breaks down into vanadium metal and iodine when it comes in contact with the hot wire, and the metal is deposited on the wire. The filament slowly grows in size in this way until it becomes many times its original size. Refining is accomplished because most of the undesirable impurities, particularly oxygen, nitrogen, and carbon, do not combine with iodine vapor to any extent under these conditions.

The final product is a spiny crystal bar of high purity vanadium metal. A typical analysis is: 99.9 pct V, 0.01 pct O_2, 0.0005 pct N_2, 0.0002 pct H_2, 0.005 pct Fe, and 0.005 pct C. Not enough is known of the properties of this very pure form of vanadium—except hardness and strength—to say whether they are significantly different from those of the somewhat less pure, but nevertheless, ductile metal.

Commercial 95 pct vanadium metal

To complete the picture of making vanadium metal, it should be pointed out that a brittle form, analyzing as high as 95 pct V, has been produced commercially for many years. It is made by the aluminothermic process, which is used to produce ferrovanadium, and is relatively high in oxygen. If the aluminum content of the metal is raised by changing the mix, the oxygen content can be lowered to less than 0.10 pct. While not in the least ductile, this metal is relatively low in price, less than $5 per lb. It can be used as the source of vanadium for some vanadium-base alloys. A refining process might perhaps be developed to make this metal ductile, at a reasonable price, and much thought is being given to this possibility.

Melting and refining

Neither the regulus resulting from the calcium reduction process nor the sponge from the magnesium reduction process is a suitable form for hot working into useful products. The vacuum-arc, consumable-electrode, cold-mold, re-melting method

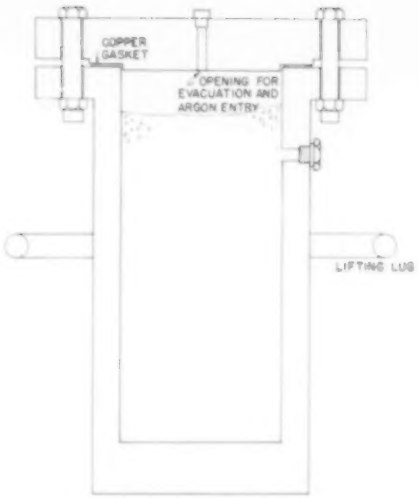

Fig. 1—Apparatus for calcium reduction of vanadium oxide.

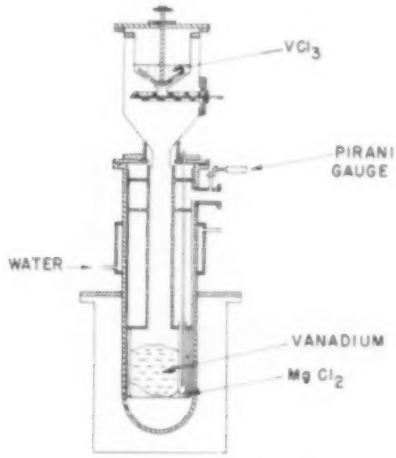

Fig. 2—Apparatus for magnesium reduction of vanadium trichloride.

appears to be the most satisfactory process for remelting these forms of vanadium into ingots. For relatively small-scale work, the calcium-reduced buttons are cut into approximately square bars and joined together end-to-end to form an electrode. For larger scale production the buttons can be joined together by welding to make a larger electrode. Sponge, of course, is pressed into an electrode shape.

The consumable-arc process has the advantage of removing part of the oxygen and hydrogen as the liquid metal drops from the tip of the electrode into the bath below through the evacuated chamber. As an example, the oxygen content of one calcium-reduced regulus was 0.12 pct before vacuum melting and 0.04 pct in the remelted ingot.

Vaccum induction melting of vanadium is feasible but not as easy as one might first think. The difficulty is that molten vanadium attacks most refractory materials, contaminating the metal with oxygen and eating through the crucible. Beryllia and thoria are the only refractories said to stand up under the attack of molten vanadium. It seems possible that these rather expensive materials might

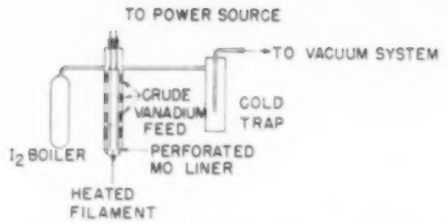

Fig. 3—Apparatus for refining vanadium by decomposition of vanadium oxide.

be used as coatings on less expensive crucibles to lower costs, but too few attempts have been made so far to know whether this is practicable. When melted in a graphite crucible, vanadium picks up carbon from the crucible. The amount can be as much as 4 pct. With larger melts, carbon pick-up apparently can be held below 1 pct.

Non-consumable, inert-atmosphere, arc-melting of vanadium is used, but the method is considered to be less desirable than consumable-arc vacuum melting.

Fabrication of vanadium metal

Vanadium of reasonable purity is ductile and can be hot worked easily. Even in this stage, however, vanadium metal requires special handling. The outstanding difference in forging or rolling between vanadium and less reactive metals is the ease and rapidity with which vanadium oxidizes at temperatures necessary for these operations. The oxide that forms when the metal is heated is V_2O_5, having a melting point of about 1225°F. Below that melting point, the oxide formed on vanadium and its alloys is tight, adherent, and self-protective. Above that melting point the oxide forms rather rapidly and runs off the metal. By alloying vanadium with titanium and other elements, oxidation resistance is improved somewhat, but not as much as would be liked.

Three approaches have been made to this problem of oxidation during hot working. The simplest is to heat and hot work the metal quickly, letting the oxide drip. Sheathing the metal in mild steel is a neater system but considerably more work. Protecting the metal in a suitable slag during heating has been encouraging, and this may prove to be the most practical method for hot working.

Experience so far has shown that once the coarse, as-cast structure of high-purity vanadium is refined by hot working, the metal is quite ductile and can be cold worked with ease. Initial forging temperatures of 2100° to 2300°F are usually required. The levels of impurities, particularly oxygen and nitrogen, appear to determine workability of the metal, both hot and cold. Precise tolerances for impurities have not yet been determined.

Mill products being rolled

The malleability of vanadium metal has been demonstrated by severe cold working operations. Foil less than 1 mil thick has been rolled without intermediate annealing. Wire of less than 15 mil diam has been drawn—and we expect it can be drawn to finer size. Wire rod is cold swaged without difficulty. To our knowledge these operations have been carried out only with relatively small ingots of vanadium. The problems of handling larger ingots

have not yet been faced. The oxidation problem may be the major one, again assuming sufficient purity.

Vanadium-titanium alloys have been found to be the only ones forgeable of eleven binary systems investigated by Rostoker, when the amount of the second element exceeded 10 pct. Addition of 0.5 to 1 pct C to the vanadium-titanium alloys has been found to improve forgeability, presumably due to the refining of the as-cast structure during freezing. Some ternary alloys have been found to be forgeable, but the amount of the third element is usually limited.

Welding of vanadium is quite practicable, but only by protecting the molten zone of the weld from the atmosphere. Methods such as Heliarc welding have been used. Welding in an inclosure having an inert atmosphere—such as a dry box—is the most satisfactory method.

Properties of ductile vanadium

In its pure form vanadium is soft and ductile. Its strength—quite sensitive to interstitial impurities—varies from about 30,000 psi in the purest form (as produced by the iodide process) to 80,000 psi in the commercial form (calcium reduced). Ductile vanadium retains its strength unusually well at elevated temperatures. At 1650°F its strength is still about 15,000 psi. This property should be useful, particularly at temperatures below the melting point of its oxide (1225°F).

There are other properties of ductile vanadium that deserve special mention. One is the relatively low neutron cross-section, 5.1 barns. This is lower than that for titanium, manganese, tantalum, tungsten, zirconium, magnesium, and boron. Much interest has been stimulated in use of vanadium in nuclear reactors as a fuel element cladding material. Its failure to alloy with uranium and good thermal conductivity are said to be the important considerations.

Corrosion resistance

Another property of special interest is the corrosion resistance of vanadium. Its resistance to hydrochloric and sulfuric acids is probably as good as any metal. Vanadium will withstand aerated salt-water attack better than most stainless steels—but not quite as well as titanium. Resistance to dilute caustic solutions is fair. Vanadium cannot withstand dilute or concentrated nitric acid.

Vanadium has a density of 6.1 gm per cu cm or 0.22 lb per cu in.—which is 22 pct lighter than iron and 28 pct denser than titanium. Coefficients of electrical and thermal conductivity are both significantly higher than those of titanium. The elastic modulus of vanadium at room temperature is of the order of 20,000,000 psi; this is substantially better than that of titanium.

The formability and unusual diffusion characteristics of ductile vanadium have resulted in serious consideration being given to the use of sheet as a diffusion barrier when cladding steel with titanium.

Properties of vanadium alloys

From the present point of view, the wider spread in properties of vanadium-base alloys seems to offer a greater prospect of application than the pure metal. It must be admitted that comparatively little has been accomplished so far in the study of alloy combinations, but some 21 binary systems have been examined at least briefly. It was found by Rostoker that 15 elements have appreciable solid solubility in vanadium. Only a few of these alloys are forgeable, as mentioned previously.

Vanadium, alloyed with titanium, has the most interesting properties of the several binary systems that have been reported. There are alloys containing 5 to 20 pct Ti which have 100-hr stress-to-rupture values of 50,000 psi at 1200°F. This is considerably better than any titanium alloy yet developed. These alloys have very substantial ductility and low flow-stresses at room temperature which promises excellent formability. They are single-phase and should have good welding characteristics. Chromium, aluminum, and zirconium show promise as ternary alloying elements. Such alloys might be considered for airframe construction of high-speed aircraft.

Vanadium-carbon alloys present some interesting possibilities. The solubility of carbon in vanadium is very small—so that the carbon exists as a fine, and intimate, mixture of very hard carbide in a softer matrix. These alloys retain significant strengths up to 1100°F. There would seem to be the prospect of applications for vanadium-carbon alloys where wear resistance at elevated temperatures is important.

Investment casting of vanadium alloys presents possibilities that appear better than for such metals as titanium, zirconium, and molybdenum. The reason is that there are refractory oxides that can apparently withstand attack by molten vanadium satisfactorily. Graphite molds might also be used for this purpose.

Summary

To summarize, ductile vanadium can now be produced from readily available ores in batches up to 45 lb by either of two reduction processes. One or both of these processes can be adapted to large-scale production should the demand arise. Remelting and fabrication methods are similar to those used for other reactive metals, and therefore they are reasonably well developed. As is the case with reactive metals, impurity levels are critical, particularly for oxygen, nitrogen, hydrogen, and carbon.

Pure vanadium is soft and ductile, has a relatively low neutron cross-section, and excellent corrosion resistance, but the metal oxidizes readily above 1225°F. Titanium appears to be the most promising alloying element for improving the strength of vanadium-base alloys, both at room and at elevated temperatures. Strength-to-weight ratio at temperatures up to 1200°F, plus good formability, appear to be among the outstanding properties studied thus far.

Just a few years ago ductile vanadium was sold at several hundred dollars per pound, reflecting the use of small-scale laboratory processes. More recently, the price of high-purity vanadium has been lowered, as manufacturing processes have been improved and production has increased. At the same time there has been an improvement in the purity and quality of the metal, and an increase in the number of forms and shapes commercially available.

Effective April 1 this year, calcium-reduced vanadium metal with 99.5 pct minimum vanadium content became available in irregular button form at a base price of $40 per lb f.o.b. producing plant. Smaller quantities and special forms and shapes command higher prices.

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7301 Euclid Avenue Cleveland 3, Ohio

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AIME NEWS

ELECTRIC FURNACE COMMITTEE

AIME Electric Furnace Steel Committee Enlarges Scope To Include Ferro-Alloy and Calcium Carbide Production

The AIME Electric Furnace Steel Committee will include production of ferro-alloy and calcium carbide within its technical scope, according to an announcement made by Victor E. Zang, Committee Chairman. Heretofore the Electric Furnace Steel Committee has been concerned only with the production of steel in electric-arc furnaces. In recognition of the change, the term *steel* has been dropped from the committee name.

The need for a continuing and central location for discussion of problems of common interest to ferro-alloy manufacturers has long existed. Literature dealing with the design, operation, and technology of arc furnaces other than for the production of steel is scant and scattered. AIME Conference techniques will be applied to this problem.

This conference technique had its origin in April, 1925, when a group of open-hearth furnace operators and metallurgists met in Pittsburgh under the auspices of AIME. From a relatively small group, the annual National Open Hearth Steel Conference has increased steadily in size, as the benefits of conducting technical meetings at an operating level proved most successful. In addition to the National Open Hearth Steel Conference, annual conferences are also conducted by two other AIME groups, the Blast Furnace, Coke Oven, and Raw Materials Committee, and the Electric Furnace Steel Committee. These committees are self-perpetuating and are semi-autonomous in their relationship to AIME. The records of their meeting—the technical papers and the discussion that follows—become a permanent part of the technical literature on steel-making through the publication of annual proceedings by each of the three Conference groups.

The Executive Committee of the Electric Furnace Committee in accepting non-steel uses of the electric-arc furnace as an integral part of the organization, has recognized this as a logical move. Arc furnaces, and submerged-arc furnaces in particular, are used not only for the manufacture of ferro-alloys and calcium carbide, but also for phosphorus, some special refractories, and abrasives. Participation by these groups is anticipated.

The objective of representatives of the major mnufacturers of ferro-alloys and calcium carbide in organizing the *Special Arc Group* is to advance the technology of the operation of electric-arc furnaces by stressing the practical rather than the highly theoretical. Solutions to operating problems confronted on a daily basis will be considered rather than detailed techniques.

Outstanding Rocky Mt. Conference Planned

The curtain will soon rise on the Fifth Annual Rocky Mountain Minerals Conference, to be staged in Salt Lake City, September 17 to 19, with outstanding technical sessions, special sessions on current engineering problems, and a symposium on modern management.

On the bill are field trips and tours to demonstrate the themes of the sessions, and a program for the ladies that will top the list of social events.

The general chairman, A. J. Thuli, has arranged a variety of topics, complete with pre-session movies on *The Copper Network* and *Columbia-Geneva Coal Preparation Plant*. There will be a discussion of education in mineral engineering and the place of automation in the mineral industry, combined with a thorough program of mineral studies including *Atomic Fuel Costs vs. Fossil Costs For Power Production; Progress in Oil Shale; Innovations in Processing Nickel and Cobalt Ores; Effect and Control of Impurities in Electrolytic Zinc Refining;* and numerous other specific subjects.

Tours will be made to Kennecott Research Laboratory, the Bureau of Mines, the new atomic reactor at the University of Utah, the Eimco Corp., and to the Western Phosphates Inc. In addition a scenic tour is planned to view Big Cottonwood Canyon.

The Honorable George D. Clyde, Governor of Utah, will give the opening day welcoming address. At the minerals luncheon on Thursday, the guest speaker will be Howard C. Pyle, President-Elect of AIME. Host for the conference is the Utah Section, R. C. Cole, chairman. The Woman's Auxiliary, with Mrs. Ralph Tuck as chairman, has prepared the ladies' events.

During the Conference, the Board of Directors of AIME will meet, as well as the Board of Directors of The Metallurgical Society and of the Society of Mining Engineers.

ABSTRACT DEADLINE
November 1

The deadline date for submission of abstracts for IMD sessions at the 1959 AIME Annual Meeting, February 15 to 19, San Francisco, is November 1, 1958. The abstracts should be between 200 to 300 words, and should be submitted in three (3) copies to:

IMD Programs Committee,
The Metallurgical Society of AIME,
29 West 39th Street,
New York 18, New York

(No photographs, diagrams, or tables should be included.)

J. H. BRENNAN

Frank J. Tone Award Announced

Joseph H. Brennan, Chief Metallurgist of the Electro Metallurgical Co., Div. of Union Carbide Corp., Niagara Falls, has been named as recipient of the Frank J. Tone Medal Award. The Medal is awarded annually by the Niagara Frontier Section of the AIME. The announcement was made by Loren W. Smith, Assistant Vice President, Symington-Gould Corp., Chairman of the Jury of Medal Award.

The Medal was established in 1956 by F. Jerome Tone and Franchot Tone to honor the memory of their father, Dr. Frank J. Tone, pioneer industrialist of the Niagara Frontier. It is awarded to a person who has made outstanding and important contributions to the science and practice of metallurgy. The recipient must be a resident of the Niagara Frontier community.

Mr. Brennan was born in Minneapolis and attended the University of Minnesota. After serving two years as an analyst with the U. S. Bureau of Mines, he joined the Electro Metallurgical Co. as a chemist in 1920. Mr. Brennan has been connected with the ferro-alloy industry during his entire career. He holds more than a dozen U.S. patents on the purification and production of metals and alloys and several times that number of foreign patents. His experience and achievements include the whole field of ferro-alloy production. Mr. Brennan is the co-inventor of a process for treating low-grade tungsten ores which was used for the larger part of America's production during World War II. He collaborated on the design, construction, and operation of the cobalt refinery which supplied most of the U.S. requirements during war years.

Mr. Brennan has served as a consultant to the National Research Council on the design of processes for complex rare metal ores and was associated in a consulting capacity with the Manhattan Project and the Atomic Energy Commission.

The Tone Medal will be presented to Mr. Brennan at the annual award meeting which will be held in Niagara Falls on November 19. The presentation will be made by Loren W. Smith, chairman of the Niagara Frontier section.

Leo F. Reinartz Scholarship Awarded

John W. Kersting of Bethel Park, Pa., has been named the 1958 recipient of the Leo F. Reinartz Scholarship. This will be the fourth year that this award has been made for a Scholarship at Carnegie Institute of Technology, alma mater of Leo F. Reinartz, former President of the Institute.

Having completed studies at St. Basil High School in Pittsburgh, John W. Kersting anticipates entering CIT this autumn. He is an eminent scholar, receiving in his early high-school years the Superlative Merit Certificate, Summa Cum Laude, in a nationwide Latin examination. In his senior year he received the Bausch & Lomb Honorary Science Award and the Certificate of Merit in the National Merit Scholarship competition, graduating from high school valedictorian with an "A" average.

John W. Kersting seems destined for high scholastic achievement at Carnegie Institute of Technology. JOURNAL OF METALS and the Metallurgical Society of AIME wish him well.

Fall Meeting NOHC, Southern Ohio

Deshler Hilton Hotel, Columbus, Ohio

Registration for the meeting will be at 8:30 am on Friday, Oct. 3, 1958.

At the MORNING SESSION Welcoming Remarks will be made by P. G. Sammet, Supt., Open Hearth, Armco Steel Corp., Ashland, Ky., who is Chairman, Southern Ohio Section of NOHC. K. C. McCutcheon, Consultant, Armco Steel Corp., Ashland, Ky., will speak on *Steelmaking Abroad*. Session chairmen are O. V. Ireland, Armco Steel Corp., Middletown, Ohio, and T. J. Murray, Armco Steel Corp., Ashland, Ky. Papers to be presented are: *Basic Quality Semi-killed Steel* by Frank Williams, Armco Steel Corp., Ashland, Ky.; *Capping Practice — Rimmed Steel* (Survey Report) by R. K. Thornberry, Acme-Newport Steel Co., Newport, Ky.; *Effect of Fast Hot-Metal Additions on Heat Time* by George Reisenberg, Armco Steel Corp., Middletown, Ohio.

At the AFTERNOON SESSION the Chairmen are Richard Thornberry, Acme-Newport Steel Co., Newport, Ky., and Tom Burney, Armco Steel Corp., Middletown, Ohio. Papers to be presented are: *Atomization of Liquid Fuel With High-Pressure Natural Gas* by Jerry Curtis, Armco Steel Corp., Middletown, Ohio; *Control of Open Hearth Heat Weight* by E. J. Whittenberger, U. S. Steel Corp., Gary, Ind.; *Progress Report on Suspended Basic Roof* by MacBeth Sample, Armco Steel Corp., Middletown, Ohio; *Application of Statistical Method for Establishing Meltdown Practice* by Oswin Eyre, Armco Steel Corp., Ashland, Ky.

Social events of the meeting will include a luncheon and dinner on Friday the 3rd of October as well as the Ohio State–Washington football game on Saturday. Toastmaster at the dinner will be V. W. Jones, National Chairman, NOHC, and the speaker is Dr. Tennyson Guyer of Findlay, Ohio.

Board of Directors Endorses Columbium

The Board of Directors of the Institute, at its last meeting, passed a resolution endorsing columbium as the proper name for the 41st element. This action is in opposition to the International Union of Pure and Applied Chemistry and the American Chemical Society, both of which have endorsed niobium as the rightful name.

The history of this long standing dichotomy was explored in the October, 1957 issue of JOURNAL OF METALS (see *Who Threw the Monkeywrench into the Periodic Table?*, p. 1350). It was the feeling of the Board that since columbium is the historically proper name, and since it is referred to commercially as columbium, both historical propriety and the balance of equities was in favor of the name columbium.

Members of the Institute are urged to adopt the name columbium, if they have previously used niobium. This particularly applies to authors who are presenting papers at meetings or preparing papers for publication, as it is only by abstention from using the term niobium that it will, at some future date, be entirely forgotten, and the erroneous results of some nineteenth century research will have been finally laid to rest.

Italian Metallurgical Society Meets

The 8th National Congress of the Italian Metallurgical Society is to take place from September 21 to 24 in Torino. It will include technical sessions plus visits to the FIAT plant in Torino, the COGNE plant in Aosta, and the Olivetti plant in Ivrea. Address of the society is Associazione Italiana de Metallurgia, Via Moscova 16, Milano, Italy.

AIME

BOARD OF DIRECTORS

Recent actions taken by the Institute Board of Directors.

► Ernest Kirkendall has been appointed one of the AIME Pension Trustees.

► E. R. Borcherdt and Otto Herres have been reappointed as AIME representatives for two-year terms on the American Standards Assn. Mining Standards Board.

► Douglas Ragland has been reappointed as representative for a three-year term on the Engineers' Council for Professional Development.

► Ivan A. Given was appointed AIME representative to the Annual Meeting of the Mining Society of Nova Scotia in July.

► LaVern M. Griffith was appointed representative on the ASA, Committee M24, Electrical Equipment in Metal Mines, to replace A. C. Stevenson.

► Use of the word *Columbium* for that element in all publications of the Institute was formally designated.

► John P. Nielson was appointed Chairman of the Student Chapter Affairs Committee to replace Robert F. Mehl who will be out of the country for the balance of the year.

► The revised Bylaws of the Southern Nevada Subsection of the Nevada Section were approved, subject to one correction.

► Establishment of the new Wyoming Mining and Metals Section was approved. Bylaws and a list of officers have been received.

► Procedure has been set up for selection of AIME representatives on ECPD standing and inspection committees. Recommendations for ECPD appointments will be made by cooperative action of Societies, Council of Education of AIME, and the Board of Directors.

Mid-America Minerals Conference in October

The Chase Hotel, St. Louis, Mo., will open its doors to the Mid-America Minerals Conference on Oct. 23 to 25, 1958. Among the many sessions scheduled, the following will be of interest to metalsmen.

A **Minerals Benefication** Session will be held on Thursday, Oct. 23, 1958, from 9:00 to 12 a.m. The Chairman will be R. H. Lowe, American Cyanamid Co., St. Louis, Mo.; Co-Chairman will be D. C. Speed, Minerva Oil Co., Elizabethtown, Ill.

9:00 *Recent Advances in Milling Practice*: H. A. Hoffman, St. Joseph Lead Co., Leadwood, Mo.

9:30 *Leaching Copper from Zinc Concentrates*: Norman Hedley and Howard Tabachnick, American Cyanamid Co.

10:00 *Application of Ore Dressing Microscopy*: C. G. Amstutz, Missouri School of Mines, Rolla, Mo.

10:30 *Two-Stage Cyclones at White Pine*: Virgil Lessels, White Pine Copper Co.

11:00 *Bulk Solids Flow*: Andrew Jenicke, University of Utah.

A session on **Extractive Metallurgy** will be held Friday, Oct. 24, 1:30 to 4 p.m., chairmanned by H. R. Bianco, Lead Smelting Div. of St. Joseph Lead Co.

1:30 *Developments in Cooperative Zinc Research*: John L. Kimberley, Executive Vice President and Secretary, American Zinc Institute.

2:00 *Nickel and Cobalt Extraction at Fredericktown, Missouri*: R. M. McCormick, National Lead Co.

2:30 *Mechanical Charging of Horizontal Zinc Retorts*: B. F. Buff, General Superintendent, National Zinc Co., Bartlesville, Okla.

3:00 *Continuous Strip Galvanizing at Granite City*: Eloy M. Cueto, Metallurgist, Granite City Steel Co.

3:30 *Continuous Casting of Magnesium*: John L. Scherer, Metallurgical Engineer, Dow Chemical Co., Madison, Ill.

General Social Program

Thursday, Oct. 23, 1958

Welcoming Luncheon—12 Noon Speaker: Felix Wormser, Vice-President of the St. Joseph Lead Co., *Economic Conditions in the Metal Industry.*

Cocktail Party—6:00 to 7:30 p.m. Sponsored by companies within the St. Louis AIME Section.

Friday, Oct. 24, 1958

Dinner Dance—7:00 p.m. Speaker: Dr. Augustus B. Kinzel, President of AIME, *Metals, Missiles, and Men.*

Plan Now for Hawaiian Sun and Sand in February

AIME announces a post-convention tour to Hawaii for ten days of sun and exotic entertainment after the Annual Meeting in San Francisco. A special flight on February 20 will carry the lucky vacationers to Honolulu for a round of sightseeing and leisure activities. Feasts and festivals, free time, and island tours fill the week's itinerary. Transportation by plane, limousine, and boat; luxurious hotel accommodations in Honolulu, Kona, and Coco Palms; special luncheons and dinners and featured programs are included in the total cost, $563.85 per person.

The holiday starts with a special welcome committee in Honolulu with music and leis and native Hawaiians. Rooms at the Hawaiian Village are ultra-modern, where guests may unwind Friday and Saturday, sleeping late or taking a dip. An afternoon tour includes Honolulu, Mt. Tantalus, the University of Hawaii, and the Monoa Valley. Sunday plans are open, with canoe and catamaran available, and an evening feast, the luau, with music and dancing.

After a lazy weekend the sightseeing begins with a 109-mile drive around the island of Oahu. Historic sites, the Mormon Temple, Pearl Harbor, and lush pineapple fields highlight the day. Tuesday again is free, and Wednesday the group flies to Hilo to visit the volcano area, flying from there on Thursday to the Island of Kauai to stay at the Coco Palms Hotel, and Friday morning a drive to Kalalau Lookout, 4000 ft high, overlooks the Napali Cliffs and Valley of the Lost Tribe. On Saturday a cruise up the Wailua River climaxes the tour before flying home.

The total price includes 12 meals, round trip tourist flight from San Francisco and all group transportation, admissions, lodging, and sightseeing outlined in the itinerary. Other meals, gratuities, laundry, and personal items not included. The tour is open to all Annual Meeting registrants.

Reservations should be made through the Theilig International Tours Inc., Daily News Plaza, Suite 2111, 400 W. Madison St., Chicago 6, Ill. The dates of the holiday are February 20 to March 1, 1959, and early reservations will be appreciated.

New York Scene of April EUSEC Conference

A five-day conference of representatives of engineering societies of western Europe and the United States was initiated in America, April 28 to May 2. The Sixth Conference of EUSEC convened at the Hotel Roosevelt, New York, with 23 societies from 14 countries represented.

(Continued on page 626)

EUSEC Conference

(Continued from page 625)

A decade ago, three British engineering societies invited the national societies of Europe and the United States to found the organization which has subsequently met in The Hague, Paris, and Copenhagen.

Louis R. Howson, president, ASCE, welcomed the conferees in New York. Items discussed included the important concerns of the profession that have been studied since the inception of EUSEC, the prime topic being the education of engineers.

AIME President Augustus B. Kinzel was in charge of the opening business session. AIME Vice President J. L. Gillson was chairman of the fourth business session, and President Kinzel presided at the closing formal dinner.

Management of EUSEC's responsibilities was formally transferred to the American societies by the retiring General Secretary of EUSEC. William Wiseman, executive secretary of ASCE, was named general secretary, and O. B. Shier, secretary of ASME, became editor of the EUSEC Bulletin. The New York conference included the following participants:

Belgium, Société Royale Belge des Ingénieurs et des Industriels; *Denmark*, Dansk Ingeniorforening; *Finland*, Samarbetsdelegationen i Finland; *France*, Société des Ingénieurs Civils de France; *Germany*, Verein Deutscher Ingenieure; *Holland*, Koninklijk Instituut van Ingenieurs; *Italy*, Associazione Nacionale Ingegneri ed Architette Italiana; *Norway*, Den Norske Ingeniorforening; *Portugal*, Ordem dos Engenheires; *Spain*, Instituto do Ingenieros Civiles de Espana; *Sweden*, Svenska Teknologförening; *Switzerland*, Schweizerischer Ingenieur und Architekten Verein; *United Kingdom*, The Institution of Civil Engineers, The Institution of Mechanical Engineers, and Institute of Electrical Engineers; *United States*, ASCE, AIME, ASME, AIEE, AIChE, UET, ECPD, and EJC.

French Metallurgical Society to Hold Fall Meeting in Paris

The Société Francaise de Métallurgie will hold its Fall Meeting in Paris, October 20-25 on the following topics: 1) Influence of residual or trace elements on the properties and working of ferrous and nonferrous metals; 2) Study of the mechanisms of the rupture of metals.

American metallurgists are invited to participtate in the meeting. Those interested in presenting papers should correspond with *E. Dupuy, Secretary General, at the Society's offices on 25 Rue de Clichy, Paris 9, France.*

European Corrosion Report Available

The *Annual Report for 1956 of the European Federation of Corrosion* and its member societies was recently published. The European Federation of Corrosion represents an association of technical and scientific societies concerned with the research on corrosion and the protection of structural materials throughout Europe.

The report is edited by the Frankfort Office of the General Secretariate of the European Federation of Corrosion which is managed on an honorary basis by the DECHEMA (Deutsche Gesellschaft für Chemisches Apparatewesen). Appearing in the form of a duplicated typewritten manuscript of 123 pp, the report may be obtained from the Frankfort Office of the General Secretariate of the European Federation of Corrosion, Frankfort, (Main) 7, Postfach, Germany. Price $3.90. The cost of postage must be borne by the addressee.

Symposium On Intermetallic Compounds

A projected symposium on the Mechanical Properties of Intermetallic Compounds is to be held during the 115th meeting of The Electrochemical Society of Philadelphia, from May 3 to 7, 1959. For the purpose of this symposium, intermetallic compounds will be held to comprise all intermediate phases in binary or higher order systems of true metals, including super-lattices. Interstitial compounds of metals and non-metals such as carbides, nitrides, borides, etc., will not be considered.

It is hoped that papers covering the following topics may include: **Fundamental Behaviors**—deformation modes, initiation and propagation of fracture, effects of crystal structure, dislocations in intermetallic compounds, influence of point defects, radiation damage; **Phenomenology**—effects of processing variables, temperature dependence of mechanical properties, effects of impurities, effects of alloying, effects of stress state and strain rate; **Experimental Techniques**—testing techniques applicable to brittle compounds, preparation of intermetallic compounds with reference to mechanical properties studies, e.g. single crystal high purity samples.

Notification of titles and authors of proposed papers should be sent immediately and triplicate copies of 75-word abstracts sent by Jan. 1, 1959 to *Dr. J. H. Westbrook, General Electric Research Laboratory, P. O. Box 1088, Schenectady, N. Y.*

Arrangements can be made for foreign authors who wish to have papers presented "in absentia".

CORRECTION

On p. 486, the July issue of JOURNAL OF METALS, L. C. Campbell was mistakenly listed as an Incumbent AIME Vice President, *Society of Mining Engineers.*

Mr. Campbell should have been correctly named as an AIME Director for 1959, *Society of Mining Engineers.*

Successful Pacific Northwest Regional Conference Held

The annual Pacific Northwest Regional Conference, scored a hit in Spokane, April 17 to 19, with the Columbia Section and its Subsections as hosts. Cooperating organizations for the conference were the AIME Oregon Section and Northern Pacific Sections, Mining Bureau of the Spokane Chamber of Commerce, the Northwest Mining Assn., and mineral industry companies in the area.

Two days of technical sessions and gay social events were crowned with field trips to nearby areas—the new Gladding McBean Co., brick plant at Mica, Wash., and the Dawn Mining Co.'s mill at Ford, Wash. and Midnight Mine at Wellpinit, Wash.

For the minerals beneficiation and extractive metallurgy people there were two sessions. The first dealt with such materials and processes as phosphate rocks, flotation of chromite from olivine, manganese oxides, and autunitic ores. Interest over the past years in uranium was reflected in the second session. Ion exchange for recovery of vanadium from uranium leach liquors and pressure leaching in uranium leaching were two of the processes described. Also discussed was application of a shrouded impeller for uranium solvent extraction.

Personals

(Continued from page 558)

Harry B. Burrack, is now serving as technical superintendent of Olin Aluminum division rolling mill of Olin Mathieson Chemical Corp., located between Clarington and Hanibal, Ohio.

Neil J. Culp and **Samuel M. Purdy,** were recently promoted by the Carpenter Steel Co., Reading, Pa., to supervisory posts in the metallurgical dept. Culp, is serving in charge of alloy development; and Purdy is now in charge of metallography.

James H. Moore, previously with Metals Hydrides Inc., Beverly, Mass., has joined the NCR Equipment Corp., a subsidiary of National Research Corp., Newton Highlands, Mass., as vice president and general manager.

1959 Nuclear Congress

The 1959 Nuclear Congress to be held in Cleveland, Ohio, April 5-10, 1959, will consist of the Nuclear Engineering and Science Conference, the Atomic Energy Management Conference, Hot Laboratories and Equipment Conference, and the Atomfair. The AIME will again be co-sponsor of this most important annual meeting on nuclear energy for peaceful purposes.

Authors are invited to submit summaries of proposed papers for presentation at the NE&S Conference under AIME sponsorship. The summaries of 300 to 500 words should be submitted in duplicate by the deadline of October 1st, 1958, for consideration by the Program Committee.

Summaries should be mailed to the AIME representative:

Mr. H. H. Chiswik
Argonne National Laboratory
Box 299
Lemont, Illinois

AROUND THE SECTIONS

Seated at the guest table during the dinner-meeting of the Southern Nevada Subsection at the Hacienda Hotel on May 7, 1958, were, left to right: L. T. Eck, Program Chairman; D. L. Day, Secretary-Treasurer; W. R. Hibbard, Jr., President of The Metallurgical Society of AIME; L. T. Hartzell, Chairman; and R. V. Lundquist, Vice Chairman.

The Red Coach Inn, Niagara Falls, N.Y., opened its doors to the **Niagara Frontier Section** on June 17, 1958. Twenty-eight persons attending heard speaker, David Swan, Linde Div., Union Carbide Corp., briefly discuss his *Observation of Russian Technical Education and Industry*, based on a trip to the USSR last fall. A film presentation, *Milling and Smelting the Sudbury Nickel Ores*, was shown through the courtesy of International Nickel Co. New officers were installed at the meet. They are: chairman, L. W. Smith, Symington-Wayne; vice chairman, W. W. Stephens, Carborundum Metals Co.; secretary, J. D. Roach, Titanium Alloy Mfg. Div., National Lead Co.; and treasurer, D. G. Sturges, Carborundum Co. Members also witnessed the presentation of past chairman pins to David Swan, Charles Hart, and Gilbert Cox.

The **Lehigh Valley Section** gathered together at Neuweiler's Brewery, Allentown, Pa., on June 24. Some 25 section members participated in the Annual Inspection Trip of Neuweiler's Brewery, Friday, June 20. They were conducted on a tour of the plant, during which details of operation and processing were explained by a guide. Upon completion of the plant visit, refreshments were served, compliments of the Brewery.

The Colorado Oil Shale Operation was the subject of Leslie C. Richards, consulting engineer, guest speaker at the June 20th dinner-meeting of the **Oregon Section** held at Burns Restaurant, Portland, Ore. The Section wished good luck to their membership chairman, Ralph Ferguson, on his being transferred to Seattle on a new assignment with Gladding McBean.

A dinner-meeting was the bill of the **Southern Nevada Subsection of AIME**, on May 7, at the Hacienda Hotel, Las Vegas. Walter R. Hibbard, Jr., President of The Metallurgical Society of AIME was the featured speaker. He gave an interesting, illustrated account of *Russian Metallurgy*, and included a description of the life and times in Russia, which was of particular interest to the many ladies present.

J. F. B. Jackson, who relinquished his position after five years as director of the British Steel Castings Research Assn. in 1954 to join the board of A.P.V.-Paramount Ltd., the alloy steel founders of Crawley, Sussex, England, was recently appointed managing director. He has also joined the board of P.I. Castings (Altrincham) Ltd., Altrincham, Cheshire, England.

Jerome F. Kuzmick, is now president of Powder Alloys Corp., Clifton, N. J. He was previously president of Welded Carbide Tool Co. Inc.

Arthur Fleischer, formerly with Gould—National Batteries, Nicad Div. Inc., is now serving as senior scientist for Edison Laboratory, McGraw-Edison Co., West Orange, N. J.

The appointments of **Charles H. Williams** as administrative vice president, engineering; and **James B. Austin** as administrative vice president, research and technology, were recently announced by United States Steel Corp., Pittsburgh. Williams was formerly assistant executive vice president, engineering and raw materials; and Austin, who had previously served as vice president, research and technology, is continuing as administrative head of these departments.

Robert E. Lubker has been appointed to the position of director of research for Alan Wood Steel Co. He was formerly associated with the Armour Research Foundation of the Illinois Institute of Technology, Chicago.

Boro Nijhawan, director, National metallurgical laboratory, Jamshedpur, India, was the recent recipient of the award of *Padma Shri*, in recognition of his exceptionally distinguished services in the fields of science in India. The president of the Union Republic of India made the presentation on India's Republic Day.

(Continued on page 628)

Physical Metallurgy Group to Visit Brookhaven in October

The Powder Metallurgy Group of the New York Section of AIME will make a visit to the Brookhaven National Laboratory on Wednesday afternoon, October 8. The tour will begin at Brookhaven at 2:30 pm. Reservations should be made no later than October 1 with the Treasurer of the Physical Metallurgy Group, Dr. F. L. Vogel, Bell Telephone Laboratories, Murray Hill, New Jersey.

Personals

(Continued from page 627)

William A. Reich, formerly manager of advance engineering for General Electric Co., has been appointed manager of the engineering section of the company's metallurgical products dept. in Detroit.

Three vice presidents who will be responsible for the corporation's major engineering activities were recently appointed by United States Steel Corp., Pittsburgh. They are: **J. L. Young,** who was named vice president, appropriations; **J. D. Rollins,** who is now vice president, facilities planning; and **E. L. Tindall,** who was appointed vice president, design and constructon.

The 1958 *Jacob F. Schoellkopf Medal* of the Western New York Section of the American Chemical Society was recently awarded to **Robert Burns MacMullin,** senior partner of R. B. MacMullin Assoc.'s, consulting engineers of Niagara Falls, N. Y. MacMullin was honored for his original contributions to the science of chemical engineering, and for his achievements at home and abroad, particularly in the field of industrial electrolytic processes.

United States Steel Corp. recently announced the following promotions in the production department. **Oscar Pearson** has been made vice president, operations—steel; **J. F. Core** became vice president, operations—coal; and **E. B. Speer** was named general manager of operations—steel.

E. C. Roper has resigned as president of Howe Sound Co. The new Howe Sound president is **William M. Weaver,** president of Haile Mines Co.

Lawrence F. Black was recently appointed to the newly created position of manager of Utah operations, U. S. Steel's Columbia—Geneva Division.

Charles L. Thompson, previously manager of sales for the Aluminum Extrusion and Tubing Div. of Reynolds Metals Co., has joined the Magnesium Co. of America, East Chicago, Ind. as general sales manager.

Walter L. Finlay, a member of the research organization of Crucible Steel Co. of America, was recently appointed by the National Advisory Committee for Aeronautics to the NACA's subcommittee on aircraft structure.

G. F. Sipp, formerly with the Raymond Concrete Pile Co. of Delaware as an assistant supervisor of construction, is now working in Turkey, for Tippett, Abbett, McCarthy Stratton Engineers, of New York, as chief mechanical engineer.

Robert S. Rosenast recently joined Beckman Instruments Inc., instrument's systems division at Anaheim, Calif. as production manager. He previously was production manager for the Clary Corp., of San Gabriel, Calif.

Thomas M. Hogan was recently promoted to New Orleans district sales manager for Jones & Laughlin Steel Corp., New Orleans. He was formerly assistant sales manager at the New Orleans office.

I. A. Oehler was recently elected executive vice president and a director of American Welding and Manufacturing Co. He formerly was vice president in charge of operations for the firm.

Sir Chester Beatty recently retired from the board of directors of American Metal Co. Ltd. of which he had been a director since 1930. Sir Chester, until 1950 was chairman of Selection Trust Ltd., and of Rhodesian Selection Trust Ltd.

Oskar Mattiat, formerly with the Institute of Technology, Munich, Germany was recently appointed to the engineering staff of Aero-physics Development Corp., a Curtiss-Wright subsidiary.

Change of Address and Personals Form

To be sure that you receive your publications and correspondence promptly, please fill in the form below and send it to **The Metallurgical Society of AIME**, 29 W. 39th St., New York 18, N.Y.:

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Personals: Please list below your former company and title and your new title and company (or new work) for use in JOURNAL OF METALS. (Copy deadline for personals items is six weeks before date of issue.)

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Former Title _____ Length of Time There _____

New Company _____

New Title _____ Date of Change _____

Any recent activity that would be of interest to members:

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I consider the following person to be qualified for membership and request that a membership kit be mailed to him:

Name of Prospective Member:

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Donald W. Johnson, secretary-treasurer of the Oregon section of AIME has become plant manager of Reynolds Metals Co., Longview, Washington aluminum reductions operations. He succeeded **V. G. Kneeskern,** who has been named manager of Reynolds Metals new St. Lawrence aluminum reduction plant at Massena, N. Y.

James A. Glunt has been appointed chief metallurgist for Alan Wood Steel Co., Conshohocken, Pa. Prior to joining Alan Wood, he was associated with Jones & Laughlin Steel Corp.

William R. Johnson, formerly chief research metallurgist at Associated Spring Corp.'s research center in Bristol, Conn., has been appointed assistant director of research and development for the company.

Peter C. Rossin has been promoted to technical director of the new refractomet div. recently established by Universal-Cyclops Steel Corp. at Bridgeville, Pa. He was formerly manager pilot-plant section of the company's research and development dept.

Willard H. Hawley, Jr., previously with the Navy Dept., Bureau of Ships is now serving as a metallurgist for the Ordnance Materials Research Office, Watertown Arsenal, Watertown, Mass.

Eugene S. Machlin, associate professor of metallurgy, Columbia University, New York, has been appointed acting director of research, Utica Metals Div., Kelsey-Hayes Co.

Paul W. Beamer, formerly supervisory engineer, casting pilot plants for Westinghouse Corp., East Pittsburgh, has joined Utica Metals Div., Kelsey-Hayes Co., as manager of sales and development.

The Jessop Steel Co. has announced the appointment of **R. E. Groeth** to the staff of the metallurgical dept. at Washington, D. C. Prior to his new appointment, he was manager of the metallurgical dept. for Corning Glass Works, Corning, N. Y.

Spencer R. Milliken, previously associated with the Aluminum Co. of America research laboratories, New Kensington, Pa., has joined Foote Mineral Co., Philadelphia, as research and development-sales staff coordinator.

Walter Bonsack has become associated with Aluminum and Magnesium Inc. as chief metallurgist and will have his headquarters at the central office in Sandusky, Ohio.

John M. Thomas, formerly manager of Hoskins Mfg. Co.'s metallurgical research and development dept., has been appointed vice president in charge of new product development for the Detroit concern.

Free Cobalt Book

A revised, 125 pp., bound edition of the bibliography, **Cobalt and its Alloys** is now available from the Cobalt Information Center. Direct requests on Company letterhead to the *Cobalt Information Center, c/o Battelle Memorial Institute, 505 King Ave., Columbus 1, Ohio.*

This reference work by Dr. F. R. Morral presents a summary of allotropy and phase diagrams. The section on allotropy contains over 90 references to literature from 1911 to 1958. Two-color phase diagrams for the cobalt binary alloys are included, as well as more than 900 references to binary, ternary, and quaternary systems. A letter code has been included to assist the reader in rapid selection of appropriate references.

Interested persons overseas may obtain copies from the *Centre d'Information du Cobalt, 35, rue des Colonies, Brussels, Belgium.*

OBITUARIES

William R. Grunow (Member 1915) passed away on Mar. 9, 1958. Born in New Haven, Conn. in 1890, Mr. Grunow graduated from Columbia University in 1912 with a B.S., and in 1914 received his E.M. degree from Columbia School of Mines. At the time of his death, Mr. Grunow was residing in Tarrenton, Pa.

George E. Harike (Member 1954) died on Nov. 28, 1956. A native of Hattiesburg, Miss., he was born on Sept. 23, 1908. Mr. Harike attended the University of Alabama from 1925 to 1929, and graduated with a B.S. degree in Chem. Eng. His past positions include that of assistant director, research laboratories, Tennessee Corp., College Park, Ga., from 1947, and assistant director, chemical research, Tennessee Copper Corp., Copper Hill, Tenn. from 1935 to 1947. At the time of his passing, Mr. Harike was living in College Park, Ga.

MEMBERSHIP

Proposed for Membership Metallurgical Society of AIME

Total AIME membership on June 30, 1958 was 33,226; in addition 3,064 Student members were enrolled.

ADMISSIONS COMMITTEE

J. H. Scaff, Chairman; Alfred Bornemann; F. B. Foley; T. D. Jones; L. L. Seigle; J. M. Warde; H. K. Work.

The Institute desires to extend its privileges to every person to whom it can be of service, but does not desire as members persons who are unqualified. Institute members are urged to review this list as soon as possible and immediately to inform the Secretary's office if names of people are found who are known to be unqualified for AIME membership.

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Roland A. Labine, Jr., New York, N. Y.
Wolfgang A. Matejka, New York Mills, N. Y.

REINSTATEMENT—CHANGE OF STATUS

Junior to Associate

Walter C. Granger, Bessemer, Ala.

Technical Re-Election

Thor N. Rhodin, Wilmington, Del.

NECROLOGY

Date Elected	Name	Date of Death
1915	William Ranald Grunow Senior Member	Mar. 9, 1958
1954	George E. Harike	Nov. 28, 1956

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COMING EVENTS

Oct. 3-4, AIME NOHC Southern Ohio Section, fall meeting, Deshler-Hilton Hotel, Columbus, Ohio.

Oct. 9-10, AIME NOHC Southwestern Section, fall meeting, Tutweiler Hotel, Birmingham, Ala.

Oct. 10, AIME NOHC Eastern Section, annual technical meeting, Warwick Hotel, Philadelphia.

Oct. 16, AIME Utah Section, *Progress in Air Pollution Control,* Salt Lake City.

Oct. 27-30, AIME Fall Meeting of The Metallurgical Society, sponsored by the Institute of Metals Division, Carter Hotel, Cleveland.

Nov. 7, AIME Pittsburgh Section, Thirteenth Annual Off-the-Record meeting, Pittsburgh.

Nov. 11, AIME NOHC Buffalo Local Section, fall meeting, Statler Hotel, Buffalo.

Nov. 17-20, The Fourth Conference on Magnetism and Magnetic Materials, sponsored by the AIEE, in cooperation with The Metallurgical Soc. of AIME, The American Physical Soc., the Inst. of Radio Engineers, and the Office of Naval Research, Sheraton Hotel, Philadelphia.

Dec. 3-5, AIME 16th Electric Furnace Conference, Statler Hotel, Detroit.

Dec. 11, AIME Utah Section, Panel discussion on the Place of Research in the Minerals Industries, Salt Lake City.

Feb. 15-19, 1959, AIME Annual Meeting, St. Francis Hotel, Sheraton-Palace Hotel, and Sir Francis Drake Hotel, San Francisco.

Apr. 2-3, 1959, AIME Technical Conference on Stress Corrosion, Mellon Institute, Pittsburgh.

Apr. 6-8, 1959, AIME 42nd National Open Hearth Steel Conference and Blast Furnace, Coke Oven, and Raw Materials Conference, Jefferson Hotel, St. Louis.

Apr. 5-10, 1959, Fifth Nuclear Congress, Cleveland Auditorium, Cleveland.

Apr. 27-30, 1959, AIME International Symposium on the Physical Chemistry of Process Metallurgy, Penn-Sheraton Hotel, Pittsburgh.

June 13-15, 1960, first International Powder Metallurgy Conference, Hotel Biltmore, New York, under joint auspices of AIME and MPA.

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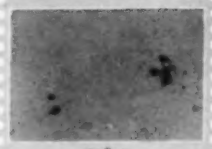

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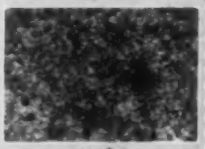

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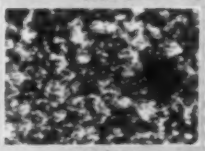

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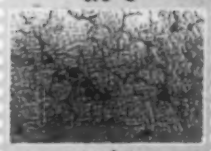

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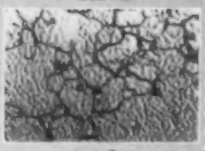

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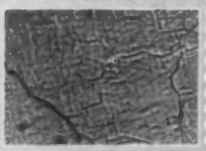

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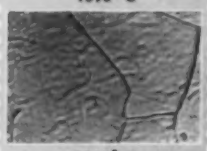

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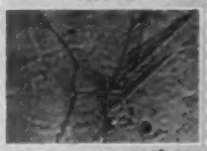

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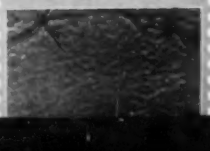

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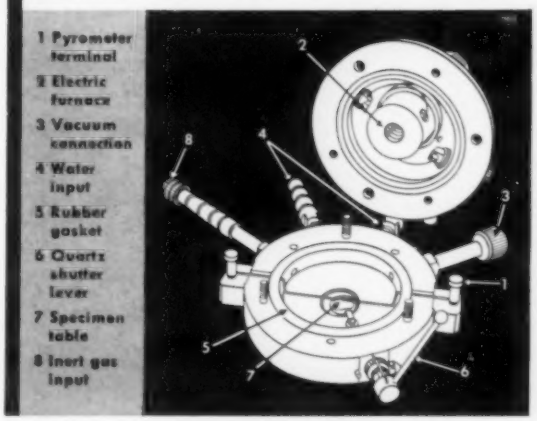

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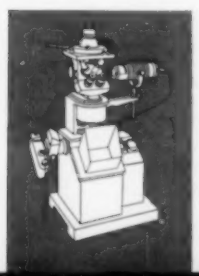

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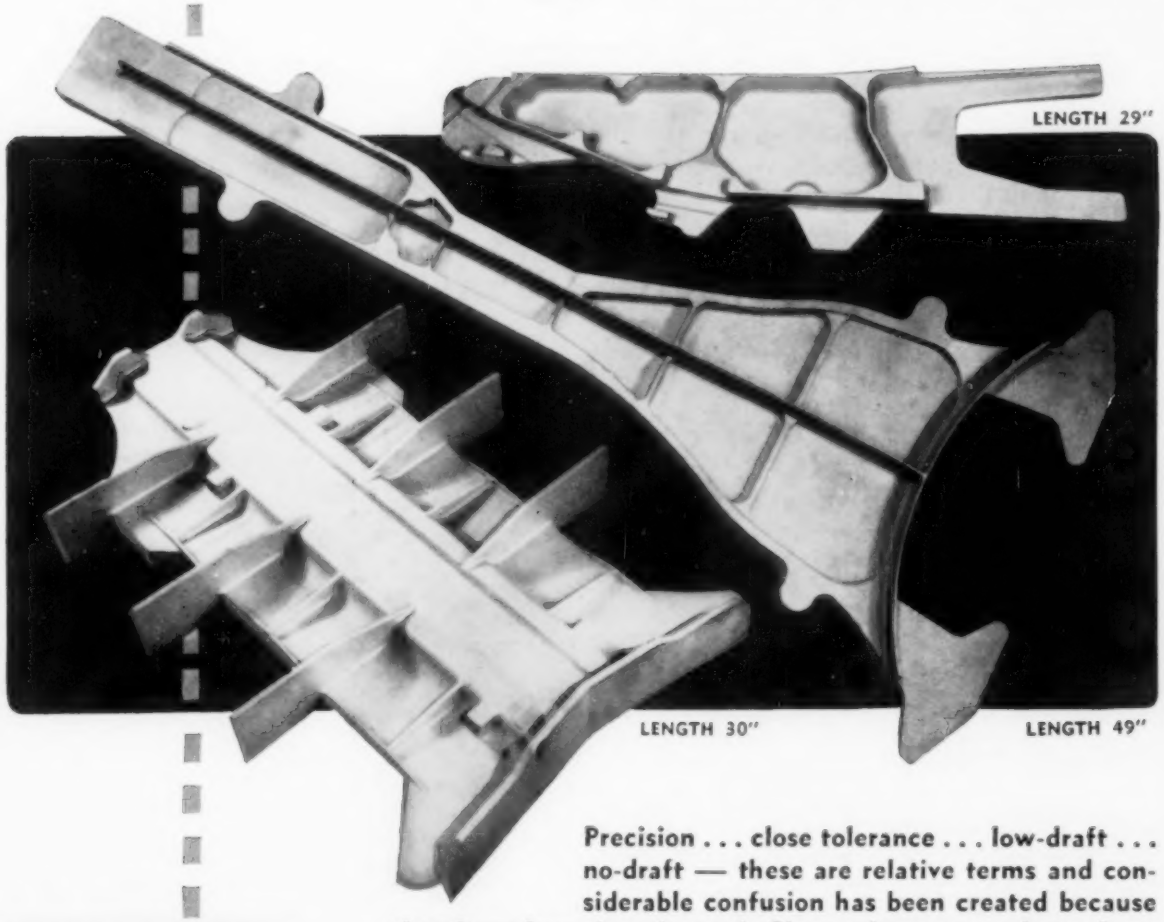
PRECISION **FORGINGS**
By WYMAN-GORDON



Precision . . . close tolerance . . . low-draft . . . no-draft — these are relative terms and considerable confusion has been created because they have been loosely used. Close tolerances on large forgings have been pioneered by Wyman-Gordon over the years. The degree of precision which is practical now becomes a question of economics.

The forgings illustrated are typical of Wyman-Gordon close tolerance forgings that have been produced in quantity. In solving problems of tolerances, design and metallurgical quality, there is no substitute for Wyman-Gordon experience.

WYMAN-GORDON COMPANY

Established 1883

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